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Effects of Dietary Crude Protein and Fiber on the Digestibility of Diets for the Young Weaned Pig

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EFFECTS OF DIETARY CRUDE PROTEIN AND FIBER ON THE DIGESTIBILITY OF DIETS FOR THE YOUNG WEANED PIG

BY

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This dissertation is approved as a creditable and independent investigation by a candidate for the degree, Doctor of Philosophy, and is acceptable for meeting the dissertation requirements for this degree. Acceptance of this dissertation does not imply that the conclusions reached by the candidate are necessarily the conclusions of the major department.

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DEDICATION

All that went into reaching this personal goal is dedicated to my mother, Linda Lou Borg, from whom I learned my most cherished lessons, the love of life and the intelligence to take nothing for granted. Thanks Mom.

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TABLE OF CONTENTS

LIST OF TABLES

Table | Page

LIST OF APPENDIX TABLES

Table | Page

Table | Page

Table | Page

EFFECTS OF DIETARY CRUDE PROTEIN AND FIBER ON THE DIGESTIBILITY OF DIETS FOR THE YOUNG WEANED PIG

ABSTRACT

BARTON S. BORG

Three experiments were conducted using a total of 30 young weaned pigs, surgically fitted with simple T-cannula at the terminal ileum, to evaluate the effects of dietary crude protein (CP) and fiber on the ileal and fecal digestibilities of various dietary fractions. Pigs (avg wt, 7.9 kg) were rotated through a series of diets in crossover designs.

Experiment 1 addressed the effect of 12.2, 17.2 and 20.8% dietary CP on ileal and fecal digestibilities of dietary dry matter (DM), nitrogen, amino acids, neutral detergent fiber (NDF), acid detergent fiber, crude fiber, cellulose, hemicellulose lignin and ash. With increasing dietary CP ileal and fecal DM digestibility decreased ($P<.03$) while nitrogen, amino acid, NDF, acid detergent fiber, crude fiber, cellulose, hemicellulose, lignin and ileal ash digestibilities all improved ($P<.05$). There appeared to be a plateau at 17.2% CP where depression in DM digestibilities and improvements in nitrogen and amino acid digestibilities were no longer significant ($P<.05$).

In experiment 2 the effects of dietary fiber on the digestibility of various dietary fractions was studied. Dietary NDF concentrations were 20.5, 24.5 and 30.5%. Crude protein was held constant at 20.8%. Increased dietary NDF depressed ($P<.05$) DM

digestibility and ileal amino acid measures but did not affect (P>.05) nitrogen, NDF, hemicellulose and ash digestibilities. Acid detergent fiber, cellulose and lignin digestibilities improved (P<.04) due to increasing dietary NDF.

In experiment 3, a factorial arrangement of 2 CP (18.6 and 24.4%) and 2 NDF (10.8 and 23.2%) concentrations were studied. Increasing dietary NDF had a negative effect (P<.05) on all dietary component digestibilities measured except lignin. Dietary NDF depressed (P<.05) amino acid digestibilities over the entire digestive tract but depressed only histidine, lysine, glycine and serine when measured at the ileum. Crude protein improved (P<.05) ileal and fecal nitrogen digestibility with little affect on amino acid digestibilities.

Fecal digestibilities of all dietary fractions measured improved with time.

Results suggest the young weaned pig is able to make limited use of fibrous diets without greatly affecting other dietary component digestibilities. Also, it may be possible to lower CP content below recommended CP concentrations without adversely affecting digestibilities. Increasing fecal digestibility coefficients over time brings to question the time period (age) at which it becomes important to use cannulated pigs for apparent digestibility measures.

PREFACE

Feed costs represent a substantial portion of the cost of swine production. Especially costly are the diets fed to young weaned pigs due to supplementation of various feedstuffs used to improve nutrient density, digestibility and palatability. Improvements in feed efficiency and daily gain along with the fact that the young pig is consuming a relatively small quantity of feed helps in making these diets seem more economically acceptable. However, these types of diets have not by any means solved all the nutritional and nutritionally related managerial and health problems associated with the early weaned pig. As age at weaning continues to decrease, milk replacer type diets, both liquid and dry, are being studied as possible improvements in meeting nutritional and palatability constraints (Jones et al., 1977). A continuing problem with the young weaned pig is a lag period following weaning during which low feed intake and possible diarrhea occur. It is not uncommon for newly weaned pigs to lose weight during the first week post-weaning. Thus, there remains a nutritional, managerial, environmental or health problem to be solved.

Armstrong and Cline (1977) reported an improvement in incidence of diarrhea when young pigs were fed diets with elevated dietary fiber concentration. Also, for years oats were added to the diets of young pigs and were noted to both improve palatability and improve the common "loose stools syndrome" experienced by the young weaned pig. However, to date the extent of fibrous diet digestibility by the young weaned pig

and its effects on nutrient digestibility are not known.

Dietary crude protein represents a substantial portion of the total cost of a young pig diet. Differences in digestibilities of various protein sources must be considered during diet formulation. For example, amino acid digestibility and availability of various feedstuffs is beginning to be defined and diets are now being formulated on the basis of digestible amino acids. This allows a better profile of amino acids to be offered to the pig by reduction or addition of protein supplement to more precisely meet limiting amino acid requirements. As digestible amino acids of more feedstuffs become defined, dietary crude protein may be decreased thus eliminating potential problems of excess dietary amino acids. Also, the improvement in crystalline amino acid production and cost will allow for supplementation of crystalline amino acids to meet limiting amino acid requirements of reduced crude protein diets. However, effect of the depression of total dietary nitrogen, on nitrogen and other nutrient digestibilities has not been studied in diets for the young weaned pig.

In monogastric animals, measurement of nutrient digestibility at the terminal small intestine (ileum) is important. Digestion or alteration of the array of digesta passing through the gastrointestinal tract, beyond the ileum, is largely due to intestinal microbes (Cranwell, 1968; Varel 1987). The fact that the pig makes very little use of nutrients appearing to be digested in the hindgut makes measurement of the nutrient digestibility at the terminal ileum important.

Thus, the objectives of this research were to study the effects of various dietary fiber and crude protein contents on the ileal and fecal digestibility of various fractions of the young weaned pigs diet.

REVIEW OF LITERATURE

Diets for the Young Weaned Pig

Research evaluating diets for the weaned pig and especially the early weaned pig has increased over the past few years due to more intensive swine production and thus the need for earlier weaning of pigs. Swine producers have for years been hampered by the problem of a post-weaning "lag period" characterized by little or no weight gain and frequently accompanied by diarrhea. This "lag period" has been described by many as a "post-weaning check period" which lasts from 7 to 14 d depending on managerial and environmental factors (Leibbrandt et al., 1975a; Rivera et al., 1978; Lecce et al., 1979).

The trend toward earlier weaning has increased the importance of reducing stress on the early weaned pig caused by low feed intake and diarrhea. One method of preventing or reducing the effect of the check period is through nutritional means. Jones et al. (1977) reported normal rates of gain by 3 to 5 week old pigs when liquid diets were fed on an hourly schedule while Thaler et al. (1985) reported improved performance of small and medium weight (10-15 lb) pigs fed high nutrient density diets (50% milk products, > 20% protein, > 1.4% lysine and > 8.0% added fat). Dietary additions of fat, flavoring agents and alternative grain sources have been evaluated in an attempt to define the optimum diet for the young weaned pig (Leibbrandt et al., 1975c; Wahlstrom et al., 1977;). Level of dietary protein and fiber have been reported to affect nutrient

utilization and subsequent growth as well as incidence of diarrhea in early weaned pigs (Menge and Frobish, 1976; Armstrong and Cline, 1977; Bourne et al., 1986).

Research to evaluate the specifics of age and its effect on protein and fiber (energy) digestibilities as well as interactions between the different dietary components in the early weaned pig is very limited. Research has been conducted pertaining to protein and energy utilization but the important issue of possible interactions between the dietary components of the early weaned pig have not been addressed.

Efird et al. (1982) studied the development of the digestive tract and its function in young pigs and reported a steady improvement in gastrointestinal tract digestive capacity up to 22 d of age with the most dramatic changes occurring between 2 to 3 weeks of age. This certainly suggests the need for tailoring diets, especially for early-weaned pigs, to meet their nutritional needs.

Leibbrandt et al. (1975a) reported pigs weaned at 2, 3 or 4 weeks of age and fed a 20% protein, 15% lard diet all experienced a post-weaning check period of essentially equal severity, however, performance at 6 weeks of age indicated there were no differences due to weaning age.

The effect of altering the calorie:protein ratio of early weaned pig diets is not clear. Leibbrandt et al. (1975b) reported additions of lard to a 20.6% protein diet resulted in depressed performance of 17 d old pigs during the initial 2 week period.

Pigs did not respond to increases in calorie:protein ratio with respect to daily gain and feed conversion until 4 weeks of age. Armstrong and Clawson (1980) reported similar results to increasing calorie:protein ratios of an 18% protein diet and also noted no improvement in performance of early weaned pigs upon feeding a higher protein level (20%). However, results reported by Menge and Frobish (1976) suggest linear improvements in daily gain of 3 week old pigs fed diets ranging from 12 to 24% protein at two calorie:protein ratios.

The effect of dietary fiber as a dietary energy diluent is not clearly defined. A review of the limited research conducted suggests that dietary fiber additions generally improve nitrogen retention while depressing energy digestibility values (De Goey and Ewan, 1975; Corley et al., 1978; Sherry et al., 1981). Rivera et al. (1978) noted no differences in pig (6 to 9 kg) performance during two 28 d feeding trials or in diet digestibility when pigs were fed diets ranging from 2.2 to 5.1% crude fiber.

Recent studies suggest early weaned pigs benefit from nutrient dense diets. However, a review of the previously cited research and consideration of production economics suggests the need for more specific information on practical dietary components and their interactions.

Methods Used in the Determination of Digestible Nutrients for Swine

The ability to accurately predict the digestibility of nutrients in swine diets is of interest and of special interest is the estimation of nutrient digestibility to the distal end of the small intestine.

Beyond this point, microbial alteration of undigested material in the cecum and large intestine change the array of undigested nutrients so that estimation of nutrients, of which the pig makes direct use of, becomes difficult (Holmes, 1974).

Many methods of measuring nutrient digestibility have been proposed and tested. For many years apparent fecal digestibilities have been used to predict digestibility of certain nutrients and types of diets (Kuiken and Lyman, 1948; Kuiken, 1952; Combs et al., 1963; Cho and Bayley, 1970; Leibholz, 1982). This method has been reported to overestimate the actual nutrients digested by the pig because of hind-gut microbial fermentation (Holmes et al., 1974; Hodgdon et al., 1977; Sauer et al., 1982b) and the inability of the cecum-colon to absorb amino acids (Just et al., 1981). Also, Salter and Coates (1971) reported fecal nitrogen excretion to be greater in germ-free chicks than in chicks reared in a normal environment and having a normal microbial population. Cho and Bayley (1972) reported that 45% and 63% of the nitrogen and amino acids, respectively, at the ileum were unrecoverable in the feces. The masking effect by inherent hind-gut microbes makes ileal estimates of nutrient digestibility of real value.

More recently, cannulation of the small intestine (usually at the terminal ileum) has been used as a method to predict digestibility of nutrients that are of use to the pig (Holmes et al., 1974, Tanksley et al., 1981; Taverner and Farrell, 1981a; Jorgensen et al., 1984; Walker et al., 1986). This method allows removal of digesta from the terminal small intestine for estimation of digestibility before entry

into the cecum and large intestine. Just et al. (1985) reported considerably higher correlations between nitrogen retention and ileal nitrogen and amino acid digestibility estimates than those estimated over the entire digestive tract.

There is, however, concern that cannulation of the intestine may alter digestibility of nutrients compared to non-cannulated, intact pigs. Laplace and Borgida (1976) and Sauer et al. (1979) reported differences in digestibilities of certain nutrients when comparing cannulated vs intact pigs. There is a possibility that cannula design (re-entrant vs T-cannulae) may have had an effect. Others (Sauer et al., 1977b; Huisman et al., 1984) have reported no differences between digestibilities of intact and cannulated pigs.

Two types of ileal cannulae have been used. Re-entrant cannulae (Easter and Tanksley, 1973; Holmes et al., 1974; Ivan and Farrell, 1976) allow total digesta collection but questions have arisen as to whether this type of cannula disturbs normal physiology of the gut (Laplace and Borgida, 1976; Sauer and Ozimek, 1983). Re-entrant cannulae shunt all digesta through a passage to the exterior of the pig. To place re-entrant cannulae the small intestine must be ligated, thus disturbing the myo-electric system of the small intestine. Also, problems with passage of digesta, with some types of diets (high fiber), have limited their use to studies in which total digesta collection is required.

The alternative to re-entrant cannulae and the type of cannula in greatest use is the simple T-cannula (Sauer and Ozimek, 1986). T-cannulae are surgically fitted into the desired position of the

intestine with minimal disturbance to the muscular or nervous system of the intestine. T-cannulae do not allow total collection of digesta so an indigestible marker is used to estimate digestibility by way of nutrient:marker ratios in diets and partially digested samples. Because total collection of digesta is not assured with T-cannulae, care must be taken to assure collection of a representative sample. Collection of a representative sample depends on many factors including cannula design, diet composition and collection procedures.

Other methods of estimating nutrient digestibility exist. Wunsche et al. (1986) indicated a positive correlation exists over various diet compositions between ileal and fecal estimates of nutrient digestibility. They reported correlations of between .87 to .93 with the highest values for cereal grains and feedstuffs of animal origin for protein digestibility and from .73 to .98 for cereals and other feedstuffs (oilseed residues, feeds of animal origin, mixed rations plus six individual feedstuffs) for lysine digestibility. They proposed that the relationship between ileal and fecal digestibility is so high that conversion from fecal to ileal digestibility can be made using conversion factors of .89 to .93 for crude protein and .92 to .99 for lysine.

Furuya et al. (1979) studied the feasibility of collecting intestinal fluid from pigs fitted with a simple T-cannula in the upper jejunum for use in measuring digestibilities <u>in vitro</u>. They reported high correlations between this method and <u>in vivo</u> techniques. They did, however, report variation in dry matter and nitrogen digestibilities.

They found *in vivo* digestibility of dry matter was greater while nitrogen digestibility was less than *in vitro* measures.

Another method of studying digestion to the point of the small intestine involves surgical attachment of the terminal ileum to the side of the descending colon (ileo-rectal shunt). Picard et al. (1985) reported amino acid digestibilities using pigs with the completed ileo-rectal shunt to be in agreement with those of pigs fitted with re-entrant cannulae.

A relatively new advent in digestibility studies is the use of the mobile nylon bag (Lange et al., 1986; Shipley and Knabe, 1986; Sauer et al., 1987). This involves inserting a small nylon bag containing approximately 1 g of the feedstuff of interest into a duodenal cannula. The bag, with contents, first undergo a pre-digest similar to conditions of the stomach. The bag and contents when excreted in the feces are then analyzed to determine digestibility. To date, only hind-gut or post-cannula site digestion can be studied due to difficulty in recovering the bag at the terminal ileum. Researchers report minimal variation in digestibilities using this method as compared to conventional methods.

Lastly, serial slaughter of pigs to determine digestibilities has been used (Low, 1982). This method is undesirable due to the shedding and sloughing of mucosal cells at slaughter thus altering apparent digestibility values.

Definition of Dietary Fiber

The term "dietary fiber" is one that is often used to describe a relatively indigestible portion of dry matter intake. Fiber addition to

human diets has gained popularity in the past few years because of the potential blood cholesterol and atherosclerosis depressing role it plays (Moore, 1967). However, the term dietary fiber has a number of definitions and it is important to understand these differences when considering the role dietary fiber plays in both human and animal nutrition.

Van Soest (1985) stated that the definition of dietary fiber will vary according to the digestive anatomy of the resective animal species. He offered a definition of dietary fiber for the monogastric as: the polymers of plant origin that are resistant to their (monogastrics) digestive enzymes. Trowell et al.(1976) defined dietary fiber for the human as those polysaccharides and related substances that are resistant to mammalian digestive enzymes. This definition includes the gums, which are hardly fibrous in a physical sense.

Robertson and Van Soest (1981) offered the following description of the components of dietary fiber:

1. Matter which is available but which escapes digestion and absorption both because transit (or passage) through the gut is rapid and because of slow digestion rates within the lower digestive tract. Competition between the rates of bacterial fermentation and transit will determine the amount that escapes to be excreted in the feces.

2. Unavailable matter which is potentially fermentable may be lost to the feces because the rate of transit is rapid compared with the rates of fermentation: in the human this relationship appears to be an important factor influencing the loss of cellulose and hemicellulose in

feces.

3. Matter which is both unavailable and unfermentable will be excreted intact in the feces. Ruminant studies show that unfermentable cellulose and hemicellulose amount to about 2.5 times the lignin content of the forage. These carbohydrates will become available to fermentation if the lignin-carbohydrate bond is broken by chemical pretreatment of the dietary fibers.

4. Microbial matter not originally present in the diet but generated through microbial action on dietary residues and endogenous secretions. The bacteria contain a large amount of protein and lipid which may represent the main sources of the increased excretion of fecal dry matter when fibrous sources are fed. About 30% of the microbial dry matter is composed of cell wall or capsular matter which is resistant to digestion by mammalian enzymes.

Regardless of the definition one chooses it is clear that dietary fiber under the former definitions, is a portion of the diet that is not readily digested by the animal itself. These definitions exclude the extensive digestion of different fractions of dietary fiber by the microflora inherent in the gastrointestinal tract of all species (Cranwell, 1968; Hofmann, 1988). This, of course, is where the difference in dietary fiber digestion and utilization occurs (ie mongastric vs ruminants). Whereas ruminant animals depend on the ruminal microflora to digest and provide nutrients from an array of relatively indigestible materials the monogastric must rely on enzymatic secretions for digestion of dry matter intake. Only in the hind-gut does an

appreciable amount of bacterial degradation occur in the monogastic animal (Cranwell, 1968; Mosenthin et al., 1986; Stanogias and Pearce, 1985b). Table 1 (Baker et al., 1979) provides one general classification of dietary fiber components.

TABLE 1. GENERAL CLASSIFICATION OF FOOD FIBER COMPONENTS

Source	Component
Plant Cell Wall	Cellulose
Structural -- Polysaccharides	Hemicelluloses
	Pectic Substances
-- Non-Carbohydrate Polymer	Lignin
Plant Non-Structural Substances and Food Additives	Pectin
	Gums
	Mucilages
	Modified Polysaccharides

Procedures and Problems with the Determination of Dietary Fiber

Along with the many different definitions of dietary fiber there are also a number of different analytical procedures for determination of dietary fiber fractions.

Determination of a fibrous fraction in feed samples dates back to 1806 when the Einhof cell wall maceration technique was used (Van Soest, 1985). However, the standard of fiber analysis over the last century has been crude fiber, which because of its estimation of only a small and variable portion of the actual dietary fiber has been suggested to be abandoned (Theander, 1981). Crude fiber analysis does not allow for the determination of indigestible and unavailable residues including part or all of the lignin, cellulose and hemicellulose fractions (Robertson and Van Soest, 1981).

Van Soest and McQueen (1973) stated the defects of crude fiber analysis to be an 80% loss of the hemicellulose fraction, 50 to 90% loss of the lignin and a loss of approximately 20 to 50% of the cellulose.

A method of fiber analysis proposed by Van Soest in the early 1960's is the detergent analysis of dietary fiber that is an attempt to fractionate plant feedstuffs in a manner consistent with the nutrient availability and fiber content of the feedstuff (Robertson and Van Soest, 1981).

Acid and neutral detergent fiber analyses are not without fault but do estimate a greater portion of what we define as dietary fiber than does crude fiber. It also, as previouly stated, separates the dietary fiber into relatively digestible (NDF) and indigestible (ADF) fractions.

The original ADF and NDF procedures used primarily for forage analysis for the ruminant specie have been modified to include analysis for soluble substances (ie pectins and B-glucans) that fall under the definition of dietary fiber for the monogastric animal (Robertson and Van Soest, 1981).

A relatively new advent in dietary fiber analysis is that of NIR or near-infrared-reflectance (Baker et al., 1979). This method of fiber analysis requires no "wet chemistry" beyond the production of a data base consisting of UV spectra and the results of chemical analyses of representative samples of various feedstuffs. Measurement of dietary fiber in a sample by NIR is conducted in the 1.4 to 2.4 um spectra. This procedure promises to be a usefull tool for the future.

Dietary Fiber and the Monogastric Animal

Traditionally pigs have been fed diets which contain large quantities of cereal grains and relatively high-value protein supplements. However, because of direct competition with man, there may be the need in certain situations to find alternative feedstuffs for pigs (Lee and Close, 1987). The feeding of by-products and more fibrous material to swine has increased over the past few years and with it has come renewed interest in the nutritional aspects of fiber utilization by swine. Lee and Close (1987) have recently reviewed the non-nutritive aspects of feeding fibrous diets including:

1. A larger volume intake increases gut fill and reduced retention time in the GI tract and may result in a more satiated, less excitable animal. Frazer (1975) reported addition of straw to the diets of sows increased the amount of time the sows spent lying down following a meal which should result in a lower energy expenditure.

2. Because diets containing fibrous material have a higher heat increment associated with the extra cost of their digestion and metabolism these diets are more useful (energetically) when fed in a cold environment. Stahly and Cromwell (1979) demonstrated that the fibrous component of the diet was more efficiently utilized by cold-stressed pigs than pigs within their thermal-neutral zone.

3. Feeding fibrous diets results in larger amount of feces with a higher dry matter content.

4. There have been reports of possible scour reducing activity

in weanling pigs fed high fiber diets.

The possible benefit of feeding high fiber diets to weanling pigs has been studied at many research stations (Smith and Halls, 1967; Armstrong and Cline, 1976; Rivera et al., 1978; Ball and Aherne, 1982) but no concrete conclusions have been suggested. Probable reasons for the scour reducing acivity that have been offered are:

1. Intake of the less palatable, lower nutrient dense diet is less and may not provide proper or optimum conditions for pathogenic bacteria proliferation.

2. More fibrous diets do not allow the fluid accumulation in the intestine which occurs with "normal" starter diets in a potential scour situation.

The effect of adding a dietary diluent (ie fiber, sand, vermiculite, polyethylene chips) is to decrease the density of other nutrients in the diet. For example, in the production of a 44% crude protein soybean meal soybean hulls are added back to a higher protein soybean meal (48%) to produce a lower crude protein soybean meal. Dietary energy concentration is probably the most important portion of the diet that is affected by the inclusion of a dietary diluent in a mixed diet. Since the pig will consume feed (assumming gut-fill does not become limiting) to meet its energy requirement a greater amount of high fiber feed is required to achieve the required energy intake (Dinusson et al., 1961). However, fibrous feeds are more bulky and often gut-fill is a limiting factor.

Much research has been conducted studying the effects of fibrous

diets fed to swine for restricting feed (energy) intake (Whatley et al., 1951; Crampton et al., 1954; Bohman et al., 1955; Merkel et al., 1958b). More recent research (Baird et al., 1970; Baird et al., 1975) suggests that other than the limitation of gut-fill with dietary fiber there are no adverse effects of fiber on growth and carcass composition. These researchers studied the effects of various dietary crude fiber concentrations at various dietary energy concentrations and reported dietary energy content was more important than was crude fiber content on growing pig performance. Also, swine carcasses have been reported to be leaner and more desirable when pigs are fed higher crude fiber, less energy dense diets (Axelsson and Eriksson, 1953; Merkel et al., 1958b; Cole et al., 1967).

Weanling pigs fed isocaloric, isonitrogenous diets including oats (10 to 30%) and kaolin (1 to 3%) as the dietary diluents performed no differently than pigs fed lower fiber diets (Rivera et al., 1978). During the 28 d trial digestibilities of crude protein, dry matter and gross energy were calculated and reported to not differ across dietary treatment. Crude fiber ranged from 2.2 to 5.1%. However, Drewry (1981) reported pigs weaned at 6 weeks of age and fed either 3.9 or 8.8% crude fiber diets differed in average daily gain during the trial. Pigs fed low fiber diets gained up to 22% faster than pigs fed the high fiber diets. Corley et al. (1978) studied the response of the weanling pig to supplementation of 2 to 6% Solka Floc to a corn-soybean meal diet. Solka Floc is a purified source of fiber containing approximately 86.6% cellulose, 7% hemicellulose and .4% lignin. Diets were made isocaloric

with addition of corn oil. Performance seemed to improve with addition of Solka Floc to the diets but results were confounded with addition of various levels of corn oil to the diets. Therefore the researchers hypothesized that the response was due to corn oil and not Solka Floc. In a second trial no corn oil was used. There was still a tendency for performance to improve with addition of Solka Floc but improvements were non-significant. Nitrogen retention was improved with addition of 4% Solka Floc to the diet.

Finishing pigs fed high fiber diets tend to increase voluntary feed intake sufficiently so as to meet daily energy requirements and not hinder performance. Cole et al. (1967) reported finishing pigs fed 8.9 or 12.9% crude fiber diets performed equally but that pigs fed the high fiber diets consumed a greater volume of feed. However, digestibilities of dry matter and nitrogen were depressed in pigs fed the high fiber diets. Owen and Ridgman (1968) added saw dust to a pelleted, high energy diet and monitored performance during three stages of the growing and finishing period. They reported that during the early stage 29.5 to 59 kg pigs fed the high crude fiber diet (12.3%) were not able to consume enough feed to meet daily energy requirements and thus pig performance suffered. However, during the final two stages 59 to 88.5 kg and 88.5 to 118 kg pigs were able to adapt to the less energy dense diet and consume enough feed to meet daily requirements. Average daily gain improved with increased daily feed intake so that no differences were noted in daily gain other than during the early stage.

The question of whether pigs adapt to higher fiber diets with

time, body weight etc. is unanswered. Partridge et al. (1982) reported digestibility of cellulose did not improve with increasing age or live weight even when dietary energy, excluding that of cellulose, was well below that required for maximal performance. Similarly, Cunningham et al. (1962) reported Solka Floc digestibility to be more influenced by level of feeding than by age of the pig. However, Gargallo and Zimmerman (1981a) and Den Hartog et al. (1986) reported improvements in cellulose digestibility with increasing age. Improvements in fibrous material digestibility with age would seem sensible for the fact that the gastrointestinal microflora, which is responsible for dietary fiber digestion, becomes more established as the pig grows older and is exposed to various microbial populations (Larson and Hill, 1955).

Effects of Dietary Fiber on Nutrient Digestibilities

It is well documented that dietary fiber affects digestibilities of various nutrients in growing-finishing swine (Lloyd and Crampton, 1955; Likuski et al., 1961; Keys et al., 1970; Sauer et al., 1980; Just, 1982; Fernandez and Jorgensen, 1986). Not only is the affect on digestibility due to dietary fiber content but more importantly to source of the dietary fiber.

Dinusson et al. (1961) fed finishing pigs a basal diet containing oat hulls to increase dietary crude fiber to 16% and reported no depression in daily gain while efficiency of feed utilization was depressed. Kornegay (1978) fed soybean hulls to 52 kg pigs and reported depression of average daily gain and an increased feed intake at a 12% addition of soybean hulls. Feed/gain was similar to a level of 6%

soybean hull inclusion then increased with increasing soybean hull addition. Acid detergent fiber, lignin and crude fiber digestibilities increased with greater quantities of hulls in the diet indicating some use of the soybean hulls. Gargallo and Zimmerman (1981b) reported essentially no fermentation of sunflower hulls in the hind-gut of finishing pigs.

Similar to the effects of adding feedstuff hulls to the diet on nutrient digestibility measures is the addition of whole seeds to the diet (Hochstetler et al., 1959; Taverner and Farrell, 1981b; Stanogias and Pearce, 1985b). Inclusion of purified forms of fiber to the diet have given indications as to why different fiber types and sources affect digestibility and performance differently (Forbes and Hamilton, 1952; Murray et al., 1977; Mitaru et al., 1984). Stanogias and Pearce, (1985a) suggested the following reasons for depressed digestibilities by various fiber sources and the variation noted between them:

1. Different effects on rate of passage through the gastrointestinal tract.

2. Increased excretion of metabolic and/or microbial nitrogen.

3. Low availability of nitrogen and other nutrients in different types of fiber.

4. Increased excretion of nitrogen or other nutrients due to lignification or entrapment in the bulk of the bolus of the fibrous digesta.

Dietary fiber concentration, whether it is measured as crude fiber, neutral detergent fiber, acid detergent fiber, lignin, purified

cellulose or relatively soluble dietary fiber such as pectin affects the digestibility and retention of various nutrients. Crude protein and amino acid digestibilities are usually depressed when finishing pigs are fed high fiber, low energy diets (Lloyd and Crampton, 1955; Whiting and Bezeau, 1957a; Likuski et al., 1961; Keys et al., 1970; Sauer et al., 1980; Just, 1982). Lloyd and Crampton (1955) reported dietary crude fiber to have three times the effect on crude protein digestibility as that of dietary crude protein itself while Key et al. (1970) reported inverse relationships between dietary crude fiber concentration and crude protein digestibilities. Likuski et al. (1961) added vermiculite to weanling pig diets as an energy diluent and reported similar effects on crude protein digestibility indicating that possibly dietary energy and not level of fiber invokes the adverse effect on crude protein digestibility. The digestibilities of crude protein, lipids, crude fiber, nitrogen free extract and gross energy were negatively influenced in pigs weighing 25, 50 and 80 kg and fed diets containing up to 14.6% crude fiber. Amino acid digestibilities were depressed both at the terminal ileum and over the entire digestive tract (Sauer et al., 1980) as crude fiber was increased in finishing pig diets while nitrogen digestibility decreased with the addition of pectin and cellulose to the diet of finishing pigs (Monsenthin et al., 1986).

Common Problems with Digestibility Studies Using Fibrous Diets

An inherent problem with digestibility studies while feeding fibrous diets is that of negative digestibility values (Southgate and Durnin, 1970; Keys and DeBarthe, 1974; Heller et al., 1980; Kass et al.,

1980; Kelsay et al., 1981; Slavin et al., 1981; Just et al., 1983; Slavin et al., 1983; Grahm et al., 1986). Digestibility of a diet or nutrient infers disappearance of that nutrient along the digestive tract. A negative digestibility, for whatever reason, suggests synthesis of the nutrient or compound in question after ingestion of the feedstuff and prior to the point of collection. Many suggestions have been offered as to why negative digestibility estimates occur. There is the possibility of chemical analyses errors. Estimation of a greater amount of compound in a partially digested sample will decrease the digestibility estimate of that compound. A number of suggested problems with analyses of neutral detergent fiber (Robertson and Van Soest, 1981) and lignin (Marlett and Johnson, 1985) have been implicated in providing the researcher erroneous results. Also, the indigestible marker used to estimate digestibility may be a problem. Fibrous diets and the digesta from ingestion of them has been reported to move in two separate phases (ie liquid and solid). The possibility exists that the marker, moving with the liquid phase, separates from the fibrous material moving in the solid phase so that digesta collection especially cranial to the cecum will not provide a representative sample of both marker and fiber (Kass et al., 1980; Just et al., 1983). Another theory for negative digestibility estimates over the entire digestive tract is the addition of microbial matter and endogenous secretions inherent in the sample collected (Grahm et al., 1986). These and other problems are being addressed but at the present time do cause one to consider results carefully before interpretation.

Crude Protein and Amino Acids

Swine require diets that provide a balanced concentration of all nutrients including crude protein/amino acids. However, pigs do not have digestible protein requirements as such, but do require certain amounts of digestible amino acids. It is important in the formulation of swine diets that digestible amino acid supply not only meet the pigs requirement but also not exceed the requirement so as to hinder performance and carcass quality (Just, 1979). For this and feed ingredient cost reasons it would be beneficial to formulate diets on a digestible amino acid basis rather than a total dietary amino acid basis.

Tanksley and Knabe (1984) suggested the possible improvement in diet formulation precision due to use of digestible amino acids would be much more evident using "alternate protein sources" such as meat and bone meal, sunflower meal, cotton seed meal and peanut meal. Because amino acid requirements have for the most part been evaluated using corn-soybean meal diets these diets already compensate for digestible amino acids and further improvement in performance due to the use of digestible amino acids is not likely. However, full or partial supplementation of crude protein/amino acids to a diet by an alternate protein source could be assisted by using previously determined digestible amino acid measures to meet daily requirements. Using this method, diets can be fine tuned to meet limiting amino acid requirements or to allow supplementation of synthetic amino acids to meet requirements.

Knabe and Tanksley (1985) adjusted diets for growing pigs containing either fish meal, peanut meal, cottonseed meal or meat and bone meal to make them equal in digestible lysine content as the corn-soybean meal control and reported improved performance of pigs fed diets formulated on a digestible lysine basis. Formulation of diets on a digestible amino acid basis can be achieved by either increasing the crude protein content or by adding individual amino acids (synthetic) to the diet.

Determination of Apparent Protein/Amino Acid Digestibility at the Terminal Ileum and in the Feces

Protein hydrolyzation, digestion and ultimate absorption occur primarily in the stomach and small intestine of swine. Twombly (1961) stated that amino acid digestion and absorption is complete by the end of the small intestine. Cho and Bayley (1972) and Low (1979) reported loss of amino acids as digesta progressed along the digestive tract. Cho and Bayley (1972) fed semi-purified diets to 60 kg pigs, sacrificed them and sampled digesta from various points along the intestinal tract. Results of digesta analyses suggested a steady loss of amino acids along the digestive tract. Low (1979) fitted 30 kg pigs with duodenal, jejunal or ileal re-entrant cannulae and reported a steady loss of amino acids as digesta transversed the small intestine.

Further digestion of protein/amino acids occurs in the hind-gut but is of little if any value to the pig (Just et al., 1981; Misir and Sauer, 1982). Therefore, digestibility of protein and amino acids, of which the pig benefits, should be measured at the end of the small intestine. Much research has been conducted studying the differences

between fecal and ileal digestibilities and support for digestibility measures at the terminal ileum continue to grow (Holmes et al., 1974; Taverner and Farrell, 1981a; Low, 1982; Sauer et al., 1982b; Rudolph et al., 1983; Just et al., 1985; Moughan and Smith, 1986).

Many factors can potentially affect the apparent digestibility of protein/amino acids when measured over the entire digestive tract. Armstrong and Mitchell (1955) reported a linear increase in fecal nitrogen excretion with increasing dietary crude protein above 8.7%. They also suggested that body weight, dietary minerals and crude fiber content, especially when intestinal motility is affected, may influence fecal nitrogen output.

The type and amount of dietary energy reaching the hind-gut also affects apparent nitrogen digestibility when measured in the feces. Misir and Sauer (1982) infused water or starch into the cecum of fistulated pigs and reported fecal nitrogen to increase when starch was infused. Although apparent nitrogen digestibility decreased with starch infusion urinary nitrogen decreased with no net change in nitrogen excretion. They suggested that increasing the fermentable carbohydrate available to the hind-gut microflora allows greater synthesis of bacterial protein from ammonia derived from the breakdown of crude protein of both dietary and endogenous origin. Thus, nitrogen excretion in the feces is greater because less ammonia is absorbed through the wall of the hind-gut and less nitrogenous compounds are excreted in the urine. Mosenthin et al. (1986) reported a similar effect due to cellulose and pectin addition to swine diets. These relatively

indigestible compounds also allow significant microbial fermentation.

Salter (1973) reported small intestinal digestion of protein/amino acids to be similar in conventional and germ-free pigs but added that hind-gut digestibility differed greatly. Total nitrogen excretion was similar in both conventional and germ-free pigs but the increased fecal excretion of nitrogen in germ-free pigs was offset by decreased urinary nitrogen excretion.

Consideration of the gut microflora and its affect on apparent protein/amino acid digestibility is an important one. The gut microflora is established relatively early in the pigs life. Etheridge et al. (1984) reported gut microflora of pigs at 21 d of age did not change as they grew older other than small increases in numbers of molds and yeasts. Low (1982) estimated that only 10% of the nitrogen found in feces is of dietary origin. This certainly suggests the need for identification of protein/amino acids of dietary origin, microbial origin, etc. or determination of digestibility prior to the large intestine.

Comparison of ileal verses fecal protein/amino acid digestibilities usually results in significant differences between digestibility at the terminal ileum or overall (Holmes et al., 1974; Sauer et al., 1982). Correlation between ileal and fecal amino acid digestibilities were reported to be good (Taverner and Farrell, 1981a) with fecal measures being approximately 4.2% greater than ileal measures. The researchers reported, however, that the difference in digestibility between the two methods increased as the digestibility of

the grain decreased. Also, Low (1982) reported the difference between ileal and fecal measures of amino acid digestibility decreases with increasing diet digestibility. These differences are likely due to the ability of the hind-gut microbes to flourish on undigested nutrients of dietary origin, thus improving apparent digestibility of relatively undigestible diets. Just et al. (1985) correlated amino acid digestibilities with protein deposition and found much higher correlations between ileal amino acid digestibility measures and protein deposition than that of fecal measures.

For the above reasons it appears the method of choice to study protein/amino acid digestibility is to study that digestion up to the terminal ileum.

Factors Affecting Apparent Crude Protein/Amino Acid Digestibilities

Many factors, some controllable others uncontrollable, affect the apparent digestibility of crude protein (nitrogen) and amino acids. Previous discussion has concerned effects of factors past the ileum. Comments in this section deal strictly with nitrogen/amino acid digestibility up to the point of the terminal ileum.

Diet composition obviously affects nitrogen/amino acid digestibility. Inclusion of fibrous materials in the diet of pigs usually decreases the digestibilities of nitrogenous compounds. Addition of fibrous material either by purified source (ie cellulose, pectin) (Mosenthin et al., 1986) or naturally fibrous feedstuffs (Just et al., 1985; Den Hartog et al., 1988) was reported to depress apparent nitrogen and amino acid digestibilities. Pectins may form gels in the gut thereby

obstructing amino acid digestibility (Sauer and Ozimek, 1986). Other dietary factors such as tannin content will also negatively influence digestibilities (Just, 1979; Cousins et al., 1981; Sauer and Ozimek, 1986). Tannins may bind to protein/amino acids forming complexes resistant to proteolytic enzymes. Crude fiber, depending on its degree of lignification, has been suggested to have the ability to adsorb amino acids and small peptides preventing absorption by the intestine. Also, there is a possibility that the digestive enzymes trypsin and chymotrypsin are bound by crude fiber rendering them useless for protein digestion (Sauer and Ozimek, 1986). Dietary protein content has been implicated as a factor in nitrogen/amino acid digestibilities. Just (1979) and Sauer et al. (1980) reported improvements in digestibility of nitrogen/amino acids as dietary protein increases but added that this effect is probably different due to endogenous nitrogen losses at various dietary protein levels.

Antibiotic inclusion has been reported to increase amino acid digestibility measured at the terminal ileum. No explanation was suggested for this effect but it does suggest a contributory effect of antibiotics on digestion and absorption of amino acids regardless of microbial population control (Just, 1979).

Variation in nitrogen/amino acid digestibility due to type of grain (Taverner and Farrell, 1981a) or protein supplement (Low, 1982; Sauer et al., 1982; Jorgensen et al., 1984) has been reported. Many of the factors effecting amino acid digestibility mentioned previously could be the reason for variation (ie crude fiber, lignin, pectins,

tannins).

Grain variety, fertilizer application and environmental growing conditions also affect amino acid composition and digestibility by altering amounts and ratios of the four major seed proteins (albumins, globulins, prolamins and glutelins) (Sauer and Ozimek, 1986).

Other factors altering amino acid digestibility in cereal grains include grain amino acid concentration. A large portion of the variation in amino acid digestibility of cereal grains is due to their relatively low concentration of amino acids., Because of this, very slight alteration in endogenous amino acid secretions will largely influence apparent amino acid digestibilities (Sauer and Ozimek, 1986). For this reason, amino acid digestibilities of proteinaceous feedstuffs are much less variable and more repeatable. Physical characteristics of cereal grains (content of hemicellulose, neutral detergent fiber, acid detergent fiber and nitrogen as well as bulk density) were reported to influence and be correlated with amino acid digestibility (Taverner and Farrell, 1981b). A problem in estimating digestibility of nitrogen/amino acids is how to deal with nitrogen and amino acids from endogenous secretions and cell sloughing. Diet composition will affect both of these factors. Dietary crude fiber content has been reported to increase the secretion of mucin protein thus altering apparent digestibility values (Taverner et al., 1981). Crude protein also may influence endogenous enzyme secretions (Low, 1979). A new method of studying endogenous nitrogen/amino acid contribution to collected samples is through the use of stable isotopes that allow differentiation between

undigested dietary and endogenous protein (Lange et al., 1987). The type of cannula used to make digesta collections has also been suggested to alter digestibility estimates. Low (1982) stated that re-entrant cannulae not only disturb the normal function of the small intestine but also may enhance microbial activity. This effect would presumably be more of a factor in the hind-gut. T-cannulae, although creating less gut disturbance, dictate the use of indigestible markers to estimate digestibility thus creating another point of possible error or variance. Finally, level of feed intake has been suggested to alter nitrogen/amino acid digestibility. However, Jorgensen et al. (1981) fed 60 kg pigs either .84 or 1.68 kg of diet/d and reported no differences in the nitrogen/amino acid digestibility. Also, Haydon et al.(1984) fed pigs ad lib, 3% or 4.5% of body weight and reported no significant nitrogen/amino acid digestibility differences but did note that digestibilities tended to decrease as feed intake decreased.

Amino Acid Digestibilities of Various Feedstuffs

During the past decade a number of research groups have studied amino acid digestibilities at the terminal ileum in many different cereal grains and protein supplements. The differences noted in amino acid digestibilities between the various feedstuffs are mainly due to the difference between the feedstuffs in the many factors influencing amino acid digestibility as previously mentioned. Due to the number of feedstuffs and amino acids within each feedstuff studied individual reports will not be discussed. However, table 2 provides references for feedstuffs of interest.

TABLE 2. REFERENCES FOR REPORTS OF AMINO ACID DIGESTIBILITIES

Reference		Feedstuff
Sauer et al., 1974	(Apparent)	Barley, Wheat, Triticale, Soybean meal
Sauer et al., 1977a	(True & apparent)	Wheat, Wheat flour, Wheat offal
Sauer et al., 1977b	(Apparent)	Corn, Wheat and Barley
Jorgenson et al., 1984	(Apparent)	Soybean meal, Fish meal, Sunflower meal and Meat and Bone meal
Knabe et al., 1985[a]	(Apparent)	Soybean meal, Meat and Bone meal, Poultry by-product, Fish meal, Peanut meal, Sunflower meal, Cottonseed meal, Corn gluten feed and Extruded soybeans
Adeola et al., 1986	(Apparent)	Triticale
Knabe et al., 1986a	(Apparent)	Wheat middlings and Brewers dried grains
Knabe et al., 1986b	(Apparent)	Ring-dried blood meal and Hydrolyzed feather meal
Knabe et al., 1986c	(Apparent)	6 meat and bone meals
Knabe et al., 1986d	(Apparent)	Corn gluten feed
LaRue et al., 1987[b]	(Apparent)	Soybean meal, Fish meal, Meat bone meal, Blood meal, Feather meal, Peanut meal, Sunflower meal, Cottonseed meal, Extruded soybeans, Poultry-by-product, Canola meal, Corn gluten meal, Corn gluten feed, Brewers dried grains and wheat middlings
Imbeah et al., 1988	(Apparent)	Barley-soybean meal or Canola soybean meal diets

[a] Nitrogen and lysine.
[b] Only tryptophan reported.

INTRODUCTION

Weaning pigs at earlier ages due to more intensive swine production practices has increased the need for knowledge of nutrient requirements as well as types of diets that will compliment the physiological status of the young pig. Recently, high nutrient dense diets have been proposed for the young weaned pig (Thaler et al., 1985) but these diets are expensive and require excellent management to make them economical. Milk products (ie dried whey and dried skim milk) have been shown to be very digestible and palatable ingredients for use in weanling pig diets. (Walker et al., 1986a). However, previous research concerning the young pig, has not addressed possible interactions of various dietary components (ie fiber and protein).

Armstrong and Cline (1977) studied the effect of increased dietary fiber content on incidence and severity of diarrhea and reported an improvement when dietary fiber levels were increased. Research with more mature swine has shown that a portion of the metabolizable energy requirement can be satisfied by bacterial fermentation of dietary fiber in the large intestine and resulting volatile fatty acid production (Rerat et al., 1987). However it is not known what ability the young pig has to utilize dietary fiber.

Dietary protein is an expensive portion of the young pigs diet. Wahlstrom et al. (1986) reported pigs fed 12, 15, 18 or 21% crude protein corn-sunflower meal diets did not differ with respect to pig performance when limiting amino acids were supplemented to the low

protein diets. Armstrong and Clawson (1980) reported no improvement in performance of early weaned pigs when dietary protein was increased from 18 to 20%. Thus, it would appear that the young pig can make excellent use of lower protein diets.

With the increasing use of digestible and available amino acid values for certain feedstuffs to formulate swine diets it is of interest to study the effect of protein level and fiber level on amino acid digestibility.

A common method of studying amino acid digestibility for pigs has been the fecal index method (Kuiken and Lyman, 1948). This method measures the amount of amino acids absorbed from the time of ingestion to the voiding of feces but does not consider the modifying action of the hindgut microflora on amino acids. More recent studies (Holmes et al., 1974; Ivan and Farrell, 1976; Sauer et al., 1977a; Jorgensen et al., 1984; Tanskley and Knabe, 1984) have shown differences in amino acid availabilities determined in feces as opposed to ileal digesta measurement. Also, Hodgdon et al. (1977) and Just et al. (1981) have shown that protein or amino acids absorbed by the hindgut provide essentially no value to the pig because they are absorbed as ammonia or amines and excreted in the urine.

With possible beneficial aspects of feeding elevated dietary fiber and lower protein diets it is important to study the effects of each of these dietary components alone and in combination. This research was conducted to study the effects of dietary fiber and crude protein on the digestibility of dry matter, nitrogen, neutral detergent

fiber, acid detergent fiber, crude fiber, cellulose, hemicellulose, lignin, ash and amino acids at both the terminal ileum and over the entire digestive tract. Also, experiment 3 was designed to study interactions of dietary fiber and crude protein content on the digestibility of the various dietary components.

EXPERIMENTAL PROCEDURE

For each of the three experiments pigs were surgically fitted with a simple T-cannula at the terminal ileum approximately 5 cm cranial to the ileo-cecal junction. Standard aseptic surgical procedures were followed. A 24 h period of no feed or water preceded surgery. Pigs were placed under general anesthesia using a mixture of oxygen, nitrous oxide and halothane. The left side of the pigs, caudal to the last rib and in the dorsal flank region, was shaved using an electric clipper and scrubbed thoroughly with iodine solution to clean and disinfect the area surrounding the incision site. An incision approximately 7.5 cm in length was made parallel and caudal to the last rib allowing enough room between the incision and last rib for cannula placement and comfortable pig movement. Following location of the ileo-cecal junction, an incision approximately 2.5 cm in length was made in the terminal ileum beginning approximately 5 cm cranial to the ileo-cecal junction and the base of the cannula was inserted. The cannula base was secured within the intestine by closure of the caudal end of the incision using a continuous stitch pattern with 2-metric polyglycolic acid suture[1]. A purse-string suture (2-metric absorbable[1]) was then placed around the base of the barrel of the cannula to further secure the cannula base within the terminal ileum. A fistula midway between the incision site and the last rib was created using a 95 mm diameter trocar. The fistula was enlarged to approximately 1.6 cm using forceps and finger manipulation. The cannula was then pulled through the fistula taking

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1. Dexon "S", Haver-Lockhart Laboratories, Shawnee Mission, KS.

care to assure that no blockage or twisting of the intestine occurred. To facilitate digesta sampling the intestine was arranged and cannula placed in the fistula so ileal digesta was forced to flow in a dorsal direction. Thus, while the pig was standing, gravity would assist in obtaining digesta samples. Cannulae were secured to the skin using 3-metric coated polyamid suture[2] previously threaded through the base of the cannula. This allowed a period of up to 14 d with minimal cannula movement to accentuate healing and adherence of the intestine to the body wall and also to maintain the intestine in the desired position for enhanced digesta sampling. The incision was closed with a series of stitches including peritoneum, muscle layers and skin using 2-metric polyglycolic acid suture[1] for peritoneum and muscle and 3-metric coated polyamid suture[2] for skin sutures. A continuous stitch was used for each layer closed. Pigs were given an injection of penicillin, removed from anesthesia and placed in steel metabolism crates (.7 X.6 m) with expanded metal flooring. Room temperature was maintained at approximately 32^{o} C during the recovery period. An 18% crude protein, corn-soybean meal starter diet was offered ad lib during the recovery period. Water was provided ad lib (nipple waterers) during the entire experiment. Pigs were given daily penicillin injections for four d following surgery. Topical antibiotic salve was applied daily to the incision to prevent infection and facilitate healing. Skin sutures were removed 10 to 14 d following surgery.

Cannulae were manufactured from materials available at a local

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2. Suprylon, Haver-Lockhart Laboratories, Shawnee Mission, KS.

hardware store including 1.6 cm PVC[3] pipe (1.3 cm internal diameter), 1.6 cm PVC T-pipe fittings, Novaweld[4] PVC cement and additional pieces made from 2.5 cm and 2.2 cm diameter PVC rod. Using these materials cannulae were tooled to desired size and shape using an electric grinder, hack saw and emery cloth. Cannula caps and retaining rings (made from PVC rod) as well as threads for the cannula barrel were made in cooperation with the SDSU engineering shop.

Crossbred pigs used in experiments 1 and 3 originated from the SDSU swine herd while pigs used in experiment 2 were purchased from a local producer. Pigs were weaned at approximately 21 d and ranged in pre-surgery weight from 6.1 to 10.0 kg.

Depending on the number of experimental treatments applied there were 3 or 4 collection periods per experiment. Each pig was sequentially rotated through each of the experimental diets and samples collected so that the number of treatments applied was equal to the number of collection periods. Collection periods were 5 d in duration with a 2 d diet adaptation period separating each period. Fecal samples were collected beginning at 0700 h on d three and ending 24 h later. Ileal digesta was collected on d 4 and 5 with collection beginning approximately 1 h post-feeding (0800 h). Ileal digesta was collected continuously until approximately 1500 h and started again 1 h after the evening meal (1800 h). Evening collections were for a three h period.

Ileal digesta was collected by attaching a 110 ml plastic bag[5]

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3. Poly-vinyl chloride.
4. Novaweld-C, Genova Inc., Davison, MI.
5. Nasco Whirl-pak, American Scientific, McGaw Park, IL.

to the cannula by tightening the twist-tie wires of the bag over and behind the cannula retaining ring. Bags were changed as needed but were never allowed to surpass 2 h before digesta was placed into the freezer. Following removal of the collection bag digesta was frozen in the collection bag in a sharp freeze at -28° C. Feces were collected by grab sampling over a 24 h period. Only newly excreted fecal matter was sampled.

Four d prior to the initiation of the experiment pigs were fed a semi-purified diet similar in nature to the experimental diets and feed intake was monitored. To equalize feed intake across diets the pig consuming the least amount of feed determined feeding level for the first period. Subsequent adjustments in feed provided were equal between individual pigs. Feed was mixed with water to form a mash and enhance feed intake. Feed was offered for a 1 h period beginning at 0700 and 1700 h. Because pigs were somewhat limited in feed intake, feed refusal was generally not a problem. When refusal or incomplete consumption did occur an estimation of feed intake was made. Composition of the experimental diets varied across experiments. However, all diets contained 8% dextrose to improve palatability. Also, .25% Cr_2O_3 was included in all diets as a digestibility marker.

Temperature of the metabolism room was similar to a nursery environment following elevated temperatures maintained for recovery. Temperatures were approximately 29° C at the beginning of the experiments and were steadily decreased as pigs matured to optimize pig comfort.

Ileal digesta and feces from individual pigs were lypholyzed then combined by period to leave one fecal and one ileal sample/pig/period. Feed samples collected during each feeding period were combined by treatment and dried in a forced air drying oven at 100° C for 24 h. All samples were ground through a 1 mm screen using a Wiley mill and a subsample ground to .75 mm for Cr_2O_3 analysis. Samples were analyzed for crude protein, crude fiber (experiment 1 and 2 only), dry matter, acid detergent fiber, lignin and ash by standard AOAC (1984) procedures. Neutral detergent fiber analysis was conducted according to the method of Van Soest and Wine (1967) with a 10 minute alpha-amylase incubation (experiment 3 only) to assist in ease of filtering (McQueen and Nicholson, 1979). Cellulose was calculated as the difference between ADF and lignin (Nahm, 1984).

Chromic oxide analysis was conducted on .2 g samples weighed into digestion tubes. Five ml of a 4:1 mixture of HNO_3 and $HCLO_4$ plus 1 ml of $HCLO_4$ was then added to the digestion tube. Best results during digestion (little foaming) were obtained if the samples were allowed to remain in the acids overnight prior to digestion. Samples were digested at 220° C for a period of time lasting 10-15 minutes beyond the point of samples turning a yellow or orange color. Care was taken to observe each tube and if any began to turn black HNO_3 was carefully added to prevent explosion. Samples were allowed to cool then diluted to 25 ml with deionized water. Solutions were then transferred to spectrophotometer tubes and optical density recorded at 440 nm.

A standard curve was prepared using 968 mg $K_2Cr_2O_7$ in 500 ml of

distilled water. This solution is a concentration such that 1 ml= 1.0 mg Cr_2O_3. Five, 10, 15, 20 and 25 ml of $K_2Cr_2O_7$ solution plus 5 ml of $HCLO_4$ were diluted to 100 ml with distilled water. Optical density of each solution was determined at 440 nm. A constant (K), was calculated as:

K = mg Cr_2O_3 per 100ml/optical density at 440nm.

% Cr_2O_3 in samples = K x od_{440nm} x 25/sample wt in mg.

Amino acids were quantitated by high pressure liquid chromatography[6] using a resin based column[7] with 6 micron particles. Pierce[8] buffers were used. Samples were hydrolyzed in 6 M HCL for 24 h at 106° C in screw cap tubes purged with nitrogen. Following hydrolysis a 200 ul sample was diluted to 100 ml with .875 ml (.1027 g/l) norleucine standard and distilled water. Samples were filtered through a 2 micron filter and a 20 ul aliquot injected.

Data for experiments 1 and 2 were analyzed as crossover designs (Damon and Harvey, 1988) measuring variation due to individual pigs, periods and dietary treatments using least-squares procedures (SAS, 1982). Treatment differences were identified through F protected LSD analysis (SAS, 1982).

Experiment 1

Five barrows and six gilts, average initial weight 9.6 kg, were surgically fitted with a simple T-cannula over a 2 d period. Pigs were allowed a 12 d recuperation period prior to the initiation of the

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6. Isco Inc., Lincoln, NE.
7. Interaction, VWR Scientific, San Francisco, CA.
8. Pierce Laboratories, Rockford, IL.

experiment. All pigs consumed feed and exhibited positive weight gain (average of 55 g/d) over the 12 d period. Nine pigs were selected for the experiment on the basis of performance during recuperation. Beginning on d 9 feed intake of a 20% crude protein, 8.6% crude fiber semi-purified sunflower meal diet was monitored for 4 d to determine level of feed intake during the initial period of the experiment. Four barrows and five gilts were allotted to experimental treatments according to weight.

TABLE 3. CHEMICAL ANALYSIS OF SUNFLOWER MEAL (%)

Item	Experiment			
	1	2		3
Moisture	10.40	11.20	7.76	9.26
Crude protein	36.30	25.60	39.50	39.70
Crude fiber	15.60	23.30	13.00	12.89
NDF	27.00	37.50	25.60	24.50
ADF	18.90	28.20	16.80	22.90
Crude fat	1.50	1.20	1.05	1.04
Ash	6.60	6.39	6.83	6.79
Lysine	1.27	1.01	1.35	1.36

Diets were formulated to contain three different crude protein levels (12, 16, 20%) while crude fiber was held constant (8.6%) with the addition of Solka Floc to diets 1 and 2. Corn-oil was added to maintain caloric content of the diets. A 36.3% crude protein sunflower meal (table 3) was used to supply dietary crude protein as well as a majority of the dietary fiber. L-threonine, L-isoleucine and DL-methionine were added to diet 1 to meet or exceed NRC (1979) recommendations while L-lysine HCL was added to all diets to maintain a 1.0 % dietary lysine concentration. Composition and chemical analyses of the experimental

diets is provided in tables 4 and 5, respectively.

TABLE 4. DIET COMPOSITION (EXP. 1, %)

Ingredient	Treatment 1	2	3
Corn starch[a]	49.27	38.62	27.90
Sunflower meal[b]	32.10	43.30	54.55
Dextrose[c]	8.00	8.00	8.00
Corn oil	.50	2.75	4.80
Dicalcium phosphate	2.00	1.40	.83
Calcium carbonate	.55	.75	.92
Salt	.30	.30	.30
Solka Floc[d]	3.90	2.00	---
Mineral premix[e]	.05	.05	.05
Vitamin premix[f]	2.00	2.00	2.00
L-lysine HCL	.76	.58	.40
L-threonine	.11	---	---
L-isoleucine	.11	---	---
DL-methionine	.10	---	---
Cr_2O_3[g]	.25	.25	.25

[a] Pearl Starch, A.E. Staley Manufacturing Co., Decatur, IL.
[b] See analysis, table 3.
[c] Staley Manufacturing Co.
[d] James River Corporation, Berlin, NH.
[e] Provided the following per kg of diet: Zn, 100 mg; Fe, 75 mg; Mn, 25 mg; Cu, 7.5 mg; I, .175 mg and Se, .1 mg.
[f] Provided the following per kg of diet: Vitamin A, 2200 IU; Vitamin D, 220 IU; Vitamin E, 11 IU; Vitamin K, 2 mg; riboflavin, 3 mg; niacin, 22 mg; pantothenic acid, 13 mg; Vitamin B_{12}, 22 ug; thiamin, 1.3 mg; Vitamin B_6, 1.5 mg; biotin, .1 mg; folacin, .6 mg and choline, 1100 mg.
[g] Chromium oxide powder 98% + purity. Aldrich Chemical Co., Inc.

Experiment 2

A total of twelve pigs (9 gilts and 3 barrows), average initial weight 7.3 kg, were surgically fitted with a simple T-cannula over a 2 d period. Pigs were allowed an 11 d recuperation period during which all pigs gained weight (average 109 g/d). Beginning on d 8 of the recuperation period feed intake of nine pigs (7 gilts, 2 barrows) was monitored to determine feeding level during the initial collection

TABLE 5. CHEMICAL ANALYSES (EXP. 1, %)

Item	Treatment 1	2	3
Crude protein	12.8	17.2	20.8
Crude fiber	8.2	8.5	8.6
Neutral detergent fiber	16.1	19.9	24.5
Acid detergent fiber	10.3	12.2	14.5
Cellulose	8.0	8.7	9.7
Lignin	2.6	3.7	4.9
Hemicellulose	5.8	7.7	10.0
Ash	4.9	5.8	6.3
Cr_2O_3	.27	.29	.27
Amino acids			
Indispensable			
Arginine	.76	1.17	1.31
Histidine	.27	.35	.43
Isoleucine	.63	.79	.89
Leucine	.82	1.23	1.34
Lysine	1.07	1.11	1.02
Phenylalanine	.50	.85	.93
Threonine	.64	.68	.84
Valine	.97	1.54	1.78
Dispensable			
Alanine	.56	.86	.93
Aspartic acid	1.59	2.02	2.60
Glutamic acid	2.82	3.44	4.52
Glycine	.58	.64	.92
Serine	.55	.64	.84
Tyrosine	.16	.21	.26

TABLE 6. DIET COMPOSITION (EXP. 2, %)

Ingredient	Treatment 1	2	3
Corn starch[a]	42.00	36.00	27.04
Sunflower meal (39%)[b]	44.80	33.00	17.00
Sunflower meal (25%)[b]	--	18.00	43.10
Dextrose[c]	8.00	8.00	8.00
Dicalcium phosphate	1.29	1.10	.72
Calcium carbonate	.80	.83	1.10
Salt	.30	.30	.30
Mineral premix[d]	.05	.05	.05
Vitamin premix[e]	2.00	2.00	2.00
L-lysine HCl	.51	.47	.44
Cr_2O_3[f]	.25	.25	.25

[a] Pearl Starch, A.E. Staley Manufacturing Co., Decatur, IL.
[b] See analysis, table 3.
[c] Staley Manufacturing Co.
[d] Provided the following per kg of diet: Zn, 100 mg; Fe, 75 mg; Mn, 25 mg; Cu, 7.5 mg; I, .175 mg and Se, .1 mg.
[e] Provided the following per kg of diet: Vitamin A, 2200 IU; Vitamin D, 220 IU; Vitamin E, 11 IU; Vitamin K, 2 mg; riboflavin, 3 mg; Niacin, 22 mg; pantothenic acid, 13 mg; Vitamin B_{12}, 22 ug; thiamin, 1.3 mg; Vitamin B_6, 1.5 mg; biotin, .1 mg; folacin, .6 mg and choline, 1100 mg.
[f] Chromium oxide powder 98% + purity. Aldrich Chemical Co., Inc.

period. An 18% crude protein, 8.6% crude fiber, semi-purified sunflower meal diet was fed over the 4 d monitoring period. Pigs were allotted by weight to experimental diets formulated to be isonitrogenous (21% crude protein) but to vary in crude fiber content (5.4, 8.3, 11.7%) and thus in dietary metabolizable energy content (3296, 3060, 2730 kcal/kg). Addition of L-lysine HCL was made to maintain dietary lysine level at 1.0%. Two sunflower meals (25 and 39% crude protein) were used to achieve desired dietary crude protein and crude fiber concentrations. Chemical analyses of the sunflower meals is provided in table 3. Composition and analyses of the experimental diets is provided in tables

TABLE 7. CHEMICAL ANALYSES (EXP. 2, %)

Item	Treatment 1	2	3
Crude protein	20.9	20.8	21.0
Crude fiber	5.4	8.3	11.7
Neutral detergent fiber	20.5	24.5	30.5
Acid detergent fiber	8.4	12.1	15.7
Cellulose	6.4	8.6	11.1
Lignin	1.9	3.6	4.1
Hemicellulose	12.1	12.4	14.8
Ash	5.8	6.2	6.6
Cr_2O_3	.26	.26	.27
Amino acids			
Indispensable			
Arginine	1.45	1.40	1.33
Histidine	.43	.43	.45
Isoleucine	.71	.67	.72
Leucine	1.21	1.13	1.24
Lysine	1.20	1.19	1.17
Phenylalanine	.85	.85	.84
Threonine	.72	.74	.76
Valine	1.29	1.23	1.08
Dispensable			
Alanine	.73	.71	.75
Aspartic acid	2.11	2.19	2.15
Glutamic acid	3.98	3.80	3.87
Glycine	.95	.90	.96
Serine	.77	.76	.81
Tyrosine	.22	.30	.29

6 and 7, respectively.

Experiment 3

Fifteen pigs (8 barrows, 7 gilts), average initial weight 6.9 kg, were surgically fitted with a simple T-cannula at the terminal ileum over a two d period. A 12 d recuperation period was planned but was extended 7 d when two of the twelve pigs used in the experiment began scouring 2 d prior to the initiation of the experiment. All pigs did exhibit weight gain (average 117 g/d) during the pre-experiment recuperation. Four d prior to the initiation of the experiment feed intake of a 21% crude protein, 3.8% crude fiber, semi-purified diet was monitored to determine feeding level during the initial collection period. Twelve pigs (5 barrows, 7 gilts) were allotted to experimental treatments according to pig weight. Experimental diets were formulated to contain two crude protein (16 and 21%) levels over two dietary neutral detergent fiber (8.3 and 18%) levels. Crude protein and NDF concentrations were achieved with addition of sunflower meal (table 3), soybean meal and soybean hulls. Sunflower meal supplied 40% of the dietary crude protein in all experimental diets. L-lysine HCL was added to the low-protein diets to equalize dietary lysine at 1.1%. DL-methionine was also included to the low-protein diets to assure adequate sulfur amino acid concentration. Composition and chemical analyses of the experimental diets is provided in tables 8 and 9, respectively.

Data were analyzed as a crossover design (Damon and Harvey, 1988) using least-squares analysis (SAS, 1982) of the factorial arrangement of treatments. Treatment variance was subdivided into

protein, fiber and protein*fiber components. The model included pig, period and treatment.

TABLE 8. DIET COMPOSITION (EXP. 3, %)

Ingredient	Treatment 1	2	3	4
Corn starch[a]	47.20	35.00	39.00	26.20
Soybean meal	19.80	16.10	27.00	23.80
Soybean hulls	3.00	19.10	--	16.20
Sunflower meal[b]	16.20	16.20	21.00	21.00
Dextrose[c]	8.00	8.00	8.00	8.00
Dicalcium phosphate	2.10	2.00	1.50	1.50
Limestone	.60	.50	.90	.70
Salt	.25	.25	.25	.25
Mineral premix[d]	.05	.05	.05	.05
Vitamin premix[e]	2.00	2.00	2.00	2.00
Antibiotic[f]	.05	.05	.05	.05
L-lysine HCl	.35	.35	--	--
DL-methionine	.15	.15	--	--
Cr_2O_3[g]	.25	.25	.25	.25

[a] Pearl Starch, A.E. Staley Manufacturing Co., Decatur, IL.
[b] See analysis, table 3.
[c] Staley Manufacturing Co.
[d] Provided the following per kg of diet: Zn, 100 mg; Fe, 75 mg; Mn, 25 mg; Cu, 7.5 mg; I, .175 mg and Se, .1 mg.
[e] Provided the following per kg of diet: Vitamin A, 2200 IU; Vitamin D, 220 IU; Vitamin E, 11 IU; Vitamin K, 2 mg; riboflavin, 3 mg; niacin, 22 mg; pantothenic acid, 13 mg; Vitamin B_{12}, 22 ug; thiamin, 1.3 mg; Vitamin B_6, 1.5 mg; biotin, .1 mg; folacin, .6 mg and choline, 1100 mg.
[f] Provided 55 mg of chlortetracycline per kg of diet.
[g] Chromium oxide powder 98% + purity. Aldrich Chemical Co., Inc.

TABLE 9. CHEMICAL ANALYSES (EXP. 3, %)

Item	Treatment 1	2	3	4
Crude protein	18.7	18.6	24.4	24.1
Crude fiber	3.9	9.7	3.8	9.6
Neutral detergent fiber	10.8	23.2	10.8	22.8
Acid detergent fiber	7.0	14.8	7.0	14.9
Cellulose	6.0	13.5	5.9	13.4
Lignin	1.4	1.5	1.4	1.6
Hemicellulose	3.8	8.4	3.8	7.9
Ash	6.3	6.5	7.2	7.3
Cr_2O_3	.28	.29	.28	.28
Amino acids				
Indispensable				
Arginine	1.07	1.12	1.50	1.45
Histidine	.39	.44	.61	.58
Isoleucine	.75	.78	1.01	.97
Leucine	1.26	1.21	1.54	1.45
Lysine	1.23	1.27	1.32	1.28
Phenylalanine	.75	.79	1.05	.99
Threonine	.82	.78	.93	.91
Valine	1.32	1.27	1.69	1.51
Dispensable				
Alanine	.85	.78	.91	.95
Aspartic acid	2.46	2.26	2.95	3.00
Glutamic acid	3.34	3.28	4.07	3.86
Glycine	.72	.75	.80	.79
Serine	.81	.76	.90	.96
Tyrosine	.13	.16	.33	.31

RESULTS AND DISCUSSION

Effects of Dietary Crude Protein and Fiber Content on the Digestibility of Dry Matter, Fiber Fraction and Ash in Diets for the Young Weaned Pig

Experiment 1

Ileal and fecal digestibility coefficients of pigs fed diets with various crude protein content is provided in table 10. Table 11 shows correlations between dietary components and the digestibility of various dietary components.

Ileal and fecal dry matter (DM) digestibility decreased ($P<.03$) with increasing dietary crude protein (CP) content. Fecal DM responded quadratically ($P<.05$) with increasing dietary CP. The response may be due more to an increasing dietary crude fiber (CF) content. Calculated dietary CF content was approximately 8.6% for all three diets. However, upon chemical analysis diet 1 analyzed to be 8.2% CF. Although differences in dietary CF content between the diets is very small CF has been reported to depress DM digestibility over the entire digestive tract (Fernandez and Jorgensen, 1986). Also, dietary CF content was equalized with the inclusion of Solka Floc but dietary neutral detergent fiber (NDF) content varied from 16.1 to 24.5%. Stanogias and Pearce (1985a) reported NDF to have a more marked affect on DM digestibility than on its own fiber component digestibility. They fed growing pigs (45 kg) diets ranging in NDF content from 7.5 to 30% and reported apparent digestibility of DM to decrease while a relatively small depression of NDF digestibility occurred.

Diet composition between the 3 experimental diets differed with

TABLE 10. DIGESTIBILITY COEFFICIENTS OF PIGS FED DIETS CONTAINING VARIOUS CRUDE PROTEIN CONTENT (EXP. 1)

		Treatment			
		1	2	3	
Crude protein, %		12.8	17.2	20.8	
Crude fiber, %	(P<)	8.2	8.5	8.6	SE[a]
Ileal DM	.03	69.62[b]	68.07[bc]	67.24[c]	.463
Fecal DM[eg]	.03	80.71[b]	79.26[c]	79.92[bc]	.411
Ileal NDF	.001	14.45[b]	27.69[c]	43.94[d]	1.49
Fecal NDF	.001	33.37[b]	47.40[c]	60.76[d]	2.03
Ileal ADF[f]	.001	4.43[b]	20.87[c]	38.22[d]	1.65
Fecal ADF	.001	23.91[b]	39.34[c]	54.85[d]	1.76
Ileal CF	.01	- 7.14[b]	.62[c]	15.91[d]	1.88
Fecal CF	.001	13.56[b]	23.39[c]	37.56[d]	2.59
Ileal cell	.001	- 7.72[b]	8.48[c]	33.56[d]	2.30
Fecal cell	.001	22.47[b]	40.06[c]	61.26[d]	2.08
Ileal hemi	.01	36.44[b]	41.24[bc]	52.70[c]	4.01
Fecal hemi	.005	54.13[b]	63.38[bc]	69.82[c]	3.35
Ileal lig	.05	41.28[b]	44.94[c]	50.79[d]	1.21
Fecal lig	.05	36.36[b]	43.88[c]	49.55[c]	2.43
Ileal ash[e]	.006	8.12[b]	14.08[c]	16.21[c]	2.62
Fecal ash		35.71	40.76	35.89	3.86

[a] Standard error of the mean.
[bcd] Means within the same row with uncommon superscripts differ.
[e] Linear response (P<.05).
[f] Linear response (P<.1).
[g] Quadratic response (P<.05).

TABLE 11. CORRELATION COEFFICIENTS OF DIETARY COMPONENTS AND RESPECTIVE COMPONENT DIGESTIBLILITY (EXP. 1)

	Dietary components							
	CP	NDF	ADF	Cell	Lignin	CF	Hemi cell	Ash
Ileal DM	-.993	-.974	-.974	-.963	-.980	-.994	-.974	-.999**
Fecal DM	-.592	-.497	-.497	-.456	-.523	-.755	-.497	-.673
Ileal N	.948	.906	.906	.886	.919	.994	.906	.976
Fecal N	.956	.983	.983	.991	.977	.868	.983	.920
Ileal NDF	.993	.999**	.999**	.999*	.999*	.942	.999**	.975
Fecal NDF	.999*	.998	.998*	.993	.999*	.965	.998*	.989
Ileal ADF	.997*	.999*	.999*	.996*	.999**	.956	.999*	.983
Fecal ADF	.998*	.999*	.999*	.995	.999**	.960	.999*	.986
Ileal cell	.984	.998*	.998*	.999*	.995	.919	.997*	.959
Fecal cell	.993	1.000**	1.000**	.999*	.999**	.944	1.000**	.977
Ileal lig	.982	.997*	.997*	.999**	.994	.916	.996*	.956
Fecal lig	.999**	.991	.991	.983	.994	.980	.991	.997*
Ileal CF	.970	.991	.991	.996*	.987	.892	.991	.939
Fecal CF	.987	.999*	.999	1.000**	.997*	.927	.999*	.965
Ileal hemi	.958	.984	.984	.991	.979	.871	.984	.922
Fecal hemi	.999*	.988	.988	.975	.991	.984	.988	.998*
Ileal ash	.947	.905	.905	.885	.918	.994	.905	.976
Fecal ash	.089	-.024	-.024	-.070	.006	.307	-.024	.194

* (P<.05).
** (P<.01).

respect to physical nature. Diet 1 contained roughly 50% corn starch while diet 3 contained approximately 28%. Sunflower meal inclusion varied from 32% in diet 1 to 55% in diet 3. Crude fiber was increased in the low protein diets with addition of Solka Floc, a purified cellulose product. Diet one had a much larger portion of the dietary DM contributed by corn starch. Since starch is a readily digestible carbohydrate source (Scott et al., 1982) digestion of that portion of the diet would be expected to be very high. The difference in DM digestibilities among the 3 diets may be due to the variation in amount of readily digestible starch. Fernandez and Jorgensen (1986) reported the digestibility of the dietary starch/sugar fraction of 7 diets to be 95% complete at the ileum and 99.6% digested in the feces. Walker et al. (1986b) reported ileal starch digestibility to be 99% in pigs similar in size to those used in our experiments. Also, the possibility exists that rate of passage of the various diets may have affected dietary component digestibilities. Rate of passage has been reported to differ due to diet composition and will affect diet digestibility (Ehle et al., 1982).

Ileal digestibility of NDF, acid detergent fiber (ADF), CF, cellulose, hemicellulose, lignin and ash all increased ($P<.05$) with increasing dietary CP content. Ileal digestibility of ADF ($P<.1$) and ash ($P<.05$) responded linearly. It is somewhat puzzling as to why dietary CP would affect the digestibility of these dietary components at the terminal ileum. There is the possibility that a lack of total nitrogen in the low protein diets could cause a depression in the

availability of digestive enzymes which are protein in nature. However, the pig does not synthesize enzymes capable of digesting the fiber fractions ADF, cellulose or a large portion of the CF, nor do they have a significant flora of cellulolytic microbes to assist in the breakdown of such dietary components (Cranwell, 1968; Stanogias and Pearce, 1985b; Mosenthin et al., 1986). Also Low (1979) and Sauer et al. (1980) reported endogenous enzyme secretion to be related to DM intake and not to vary over a wide range of CP intake. This would suggest that enzyme secretion is not altered.

Ileal CF and cellulose digestibility coefficients of pigs fed diet 1 were negative indicating a recovery of the artifact substances during chemical analysis of digesta samples. Many possible explanations may be suggested for this occurrence. Possible contribution of microbial matter not digested during fiber analysis can provide some area for error (Grahm et al., 1986). There is also the possibility of chemical analysis or indigestible marker collection problems using differing types of diets. Essentially any alteration of the actual amount of CF or cellulose in a digesta sample where virtually no digestibility of those components has occurred, would give rise to possible negative digestibility coefficients.

Fecal measures of NDF, ADF, CF, cellulose, hemicellulose and lignin digestibility were greater than those measured at the ileum but responded in a similar fashion. Fecal digestibility measures are greater than ileal measures because of the microbial digestion of compounds in the large intestine (Cranwell, 1968; Varel, 1987).

Increased digestibility of the fibrous fractions due to increasing level of dietary CP may possibly be explained as an improvement in the nutritional status of the hindgut microflora. It is well documented that type and amount of carbohydrate reaching the hindgut will influence microbial action of undigested nutrients (Mosenthin et al., 1986). If nitrogen was a limiting factor for the hindgut microbes an increased dietary nitrogen content would allow them to flourish. There is also the possibility of the increased CF content of diets 2 and 3 causing an increase in large intestinal microbial activity.

Fecal ash digestibility did not differ ($P<.05$) across dietary treatment. Etheridge et al. (1984) and Den Hartog et al. (1988) fed pigs diets of various composition and reported no variation in fecal ash digestibility. The fecal measure of ash digestibility may be a more accurate estimate of ash digestibility due to the fact that the ileal digesta contains gut secretions of high mineral content (buffers, etc.) that are not completely absorbed until passing into the large intestine. Grahm et al. (1986) reported negative ash digestibilities and explained the erroneous results as being caused by endogenous contamination. Ileal ash digestibility differences among treatments may be caused by an altered flow of endogenous material due to different diet composition (Low, 1979).

Experiment 2

Ileal and fecal digestibility coefficients as well as correlation coefficients of pigs fed diets of various CF content are summarized in tables 12 and 13, respectively.

TABLE 12. ILEAL AND FECAL DIGESTIBILITY COEFFICIENTS OF PIGS FED DIETS WITH VARIOUS CRUDE FIBER CONTENT (EXP. 2)

		Treatment			
		1	2	3	
Crude protein, %		20.9	20.8	21.0	
Crude fiber, %	(P<)	5.4	8.3	11.7	SE[a]
Ileal DM	.04	63.76[b]	61.59[bc]	58.09[c]	1.779
Fecal DM		78.85	78.20	77.88	1.795
Ileal NDF		33.40	38.10	45.65	4.694
Fecal NDF		54.28	60.21	64.76	5.647
Ileal ADF	.03	-21.70[c]	5.53[b]	26.14[b]	8.288
Fecal ADF	.01	9.66[c]	35.94[bc]	47.62[b]	9.620
Ileal CF	.01	-49.54[c]	- 7.61[a]	18.69[b]	10.586
Fecal CF		12.92	26.05	43.12	12.205
Ileal cell	.002	-17.58[c]	2.21[bc]	23.03[b]	7.857
Fecal cell	.04	27.67[c]	46.00[b]	54.27[b]	8.245
Ileal hemi		71.86	69.99	66.31	2.202
Fecal hemi		85.42	83.96	82.91	3.010
Ileal lig[d]	.003	-34.58[c]	17.91[b]	27.04[b]	10.487
Fecal lig[d]	.007	-36.33[c]	22.95[b]	32.54[b]	13.476
Ileal ash		13.28	14.76	13.24	2.022
Fecal ash		46.83	47.85	50.20	2.719

[a] Standard error of the mean.
[bc] Means within the same row with uncommon superscripts differ.
[d] Linear response (P<.06).

TABLE 13. CORRELATION COEFFICIENTS OF DIETARY COMPONENTS AND RESPECTIVE COMPONENT DIGESTIBLILITY (EXP. 2)

	Dietary components							
	CP	NDF	ADF	Cell	Lignin	CF	Hemi cell	Ash
Ileal DM	-.612	-.999**	-.989	-.995	-.904	-.996*	-.959	-.991
Fecal DM	-.323	-.953	-.982	-.973	-.993	-.971	-.816	-.981
Ileal N	-.648	-.998*	-.982	-.990	-.884	-.991	-.971	-.984
Fecal N	-.031	-.821	-.885	-.863	-.982	-.859	-.611	-.881
Ileal NDF	.611	.999**	.990	.995	.905	.996*	.959	.991
Fecal NDF	.433	.981	.998*	.994	.974	.992	.979	.997*
Ileal ADF	.429	.981	.997*	.993	.974	.992	.876	.996*
Fecal ADF	.300	.945	.978	.968	.996*	.965	.801	.976
Ileal cell	.513	.995	.999**	.999**	.949	.999**	.918	.999**
Fecal cell	.304	.946	.978	.968	.996*	.966	.803	.977
Ileal lig	.137	.877	.929	.912	.997*	.908	.691	.926
Fecal lig	.129	.872	.926	.908	.996*	.905	.684	.923
Ileal CF	.382	.970	.992	.986	.985	.984	.851	.991
Fecal CF	.297	.944	.977	.967	.997*	.964	.799	.975
Ileal hemi	-.590	.297	.411	.371	.661	.362	.005	.405
Fecal hemi	-.416	-.978	-.996*	-.991	-.978	-.990	-.870	.996*
Ileal ash	.920	.233	.112	.156	.183	.165	.516	.119
Fecal ash	.686	.993	.971	.981	.859	.983	.982	.973

* (P<.05).
** (P<.01).

Ileal DM digestibility differed (P<.04) and decreased along with ileal hemicellulose digestibility as dietary CF content increased. Stanogias and Pearce (1985a) and Fernandez and Jorgensen (1986) reported similar results due to increasing dietary CF and NDF content. Ileal DM digestibility was negatively correlated with CF (P<.05) and NDF (P<.01) content of the diet. Den Hartog et al. (1986) reported the rate of passage in the small intestine to be increased while in the large intestine decreased with greater dietary CF content. This explains a declining DM digestibility at the ileum but no difference between diets over the entire digestive tract. Fecal DM and hemicellulose digestibility did not differ (P<.05) due to dietary treatment.

Ileal and fecal NDF digestibility, while both increasing numerically, did not differ (P>.05) due to dietary treatment. Fecal NDF digestibilities were greater than ileal measures indicating hindgut microbial digestion of NDF passing into the large intestine. Correlation coefficients of ileal NDF digestibility and dietary concentrations were positive for both dietary NDF (P<.01) and CF (P<.05). Fecal NDF digestibility was positively correlated with both dietary ADF and ash content (P<.05).

The increase in NDF digestibility as dietary NDF increases is contrary to the results of King and Taverner (1975) who reported depressed NDF digestibility with increasing dietary CF or NDF when measured over the entire digestive tract. However, they used diets much higher in CF (15.8%) and did not note a response of depressed

digestibility until the high CF levels were fed. Keys et al. (1970) fed 84 kg barrows diets with cell wall (NDF) content of 14.5, 23.4 and 36.1%. They reported no differences in NDF digestibility over the entire tract.

Ileal and fecal ADF, cellulose and lignin digestibility differed ($P<.05$) due to dietary treatment while only the ileal digestibility of CF responded ($P<.01$) to increased dietary CF. All digestibilities improved with increasing CF content. Fecal measures were greater than ileal digestibilities again suggesting significant microbial digestibility in the hindgut. Ileal digestibilities of ADF, cellulose and lignin were negative for diet 1 while CF digestibilities were negative for both diets 1 and 2. Negative digestibilities have been reported by a number of research groups (Southgate and Durnin, 1970; Keys and DeBarthe, 1974; Heller et al., 1980; Kass et al., 1980; Kelsay et al., 1981; Slavin et al., 1981; Just et al., 1983; Slavin et al., 1983; Grahm et al., 1986).

Marlett and Johnson (1985) stated that most procedures developed to measure fiber in feeds will recover from digesta, in addition to dietary fiber, variable and unknown amounts of endogenously secreted mucus and bacterially synthesized exopolysaccharides. They also described negative lignin digestibilities to be caused by artifact lignin which may contain a significant amount of nitrogen thus suggesting erroneous lignin digestibility measures.

Ileal and fecal ash digestibilities were relatively constant and did not differ ($P>.05$) due to dietary treatment.

Experiment 3

Main effect and individual treatment ileal and fecal digestibility coefficients are summarized in tables 14 and 15, respectively. Correlation coefficients of ileal and fecal digestibilities and dietary components are provided in table 16. A summary of digestibility coefficients over time is provided in table 17.

Data for experiment 3 were analyzed to test for an NDF*CP interaction. However, the interaction was not significant ($P>.05$) so only main effect means will be discussed. Individual treatment means have been included for additional comparison.

Ileal and fecal DM digestibility decreased ($P<.0001$) with increased dietary NDF. There was approximately a 10% difference in DM digestibility due to increased dietary NDF. This is in agreement with the reports of Keys et al. (1970), Stanogias and Pearce (1985a) and Fernandez and Jorgensen (1986) who reported depressed apparent digestibility of DM with increasing dietary NDF when measured over the entire digestive tract. Fecal DM digestibilities were greater than ileal measures indicating hindgut microbial digestion. There was no affect due to CP content on ileal or fecal DM digestibility.

Ileal NDF digestibility improved ($P<.02$) when dietary NDF was increased from 10.8 to 23.2 %. This is in agreement with the results of experiment 2 but does not agree with reports of King and Taverner (1975) who measured digestibility over the entire digestive tract and reported a decline in NDF digestibility with increased dietary NDF.

TABLE 14. MAIN EFFECT ILEAL AND FECAL DIGESTIBILITY COEFFICIENTS (EXP. 3)

	Neutral detergent fiber			Crude protein			
	Lo	(P<)	Hi	Lo	(P<)	Hi	SE[a]
Ileal DM[b]	72.48	.0001	61.86	67.64		66.70	.939
Fecal DM[b]	84.69	.0001	73.52	78.78		79.43	.888
Ileal NDF[b]	10.27	.02	16.18	13.08		13.37	2.503
Fecal NDF[b]	43.15	.07	36.72	37.18		42.69	3.388
Ileal ADF[b]	22.58	.04	17.07	18.94		20.73	2.622
Fecal ADF[b]	38.86	.0004	24.43	28.45	.09	34.84	3.632
Ileal cell[b]	35.98	.03	25.56	30.54		31.01	4.462
Fecal cell[b]	54.95	.0001	30.98	40.08	.08	45.85	3.203
Ileal hemi[b]	-13.85	.0001	15.29	1.35		.09	5.707
Fecal hemi[b]	50.53		58.80	51.97		57.37	5.691
Ileal lig	27.18		25.36	26.98		25.56	3.606
Fecal lig	25.76		19.37	22.25		22.88	4.522
Ileal ash[b]	32.39	.0001	22.69	25.27	.02	29.80	1.828
Fecal ash[b]	51.12	.02	42.78	46.71		47.20	3.294

[a] Standard error of the mean.
[b] Significant main effect.

TABLE 15. INDIVIDUAL TREATMENT ILEAL AND FECAL DIGESTIBILITY COEFFICIENT MEANS (EXP. 3)

	Dietary treatment				
Crude protein, %	18.7	18.6	24.4	24.1	
Neutral detergent fiber, %	10.8	23.2	10.8	22.8	SE[a]
Ileal DM	73.16[b]	62.12[c]	71.80[b]	61.60[c]	.948
Fecal DM	84.72[b]	72.83[c]	84.66[b]	74.21[c]	.893
Ileal NDF	10.23	15.93	10.31	16.42	2.541
Fecal NDF	39.44	34.91	46.85	38.52	3.427
Ileal ADF	23.06	14.81	22.10	19.35	2.617
Fecal ADF	36.79[bc]	20.10[d]	40.94[b]	28.75[cd]	3.669
Ileal cell	34.73	26.34	37.24	24.78	4.521
Fecal cell	51.70[b]	28.45[c]	58.20[b]	33.51[c]	3.253
Ileal hemi	-16.13[c]	18.84[b]	-11.56[c]	11.75[b]	5.703
Fecal hemi	43.43	60.50	57.63	57.10	5.553
Ileal lig	26.86	27.10	27.51	23.61	3.646
Fecal lig	28.71	15.80	22.81	22.94	4.440
Ileal ash	31.01[b]	19.54[d]	33.76[b]	25.84[c]	1.830
Fecal ash	50.70	42.71	51.55	42.86	3.348

[a] Standard error of the mean.
[bcd] Means within the same row with uncommon superscripts differ ($P<.05$).

TABLE 16. CORRELATION COEFFICIENTS OF DIETARY COMPONENTS AND RESPECTIVE COMPONENT DIGESTIBLILITY (EXP. 3)

	Dietary components						
	CP	NDF	ADF	Cell	Lignin	Hemi cell	Ash
Ileal DM	.065	-.996**	-.997**	-.997**	-.915	-.991**	-.142
Fecal DM	.064	-.997**	-.994**	-.995**	-.862	-.999**	-.149
Ileal N	-.354	.614	.624	.626	.681	.597	-.247
Fecal N	.559	-.849	-.834	-.846	-.563	-.873	.370
Ileal NDF	.647	-.496	-.495	-.504	-.445	-.494	.558
Fecal NDF	.639	-.647	-.644	-.653	-.540	-.651	.513
Ileal ADF	-.445	.033	.044	.047	.180	.014	-.466
Fecal ADF	.505	-.887	-.877	-.886	-.664	-.902	.315
Ileal cell	.083	-.978*	-.981**	-.981**	-.931	-.969*	-.115
Fecal cell	-.139	-.881	-.875	-.874	-.706	-.891	-.339
Ileal lig	-.423	-.570	-.596	-.583	-.872	-.523	-.513
Fecal lig	.600	-.750	-.745	-.754	-.609	-.757	.448
Ileal hemi	-.074	.983**	.978*	.980**	.814	.990**	.140
Fecal hemi	.159	.880	.874	.873	.713	.888	.357
Ileal ash	.446	-.903	-.890	-.899	-.633	.924	.246
Fecal ash	-.695	.292	.292	.301	.267	.291	-.650

* (P<.05).
** (P<.01).

TABLE 17. EFFECT OF TIME ON ILEAL AND FECAL DIGESTIBILITY COEFFICIENTS OF YOUNG WEANED PIGS (EXP. 3)

	Period[a]				
	1	2	3	4	SE[b]
Ileal DM	66.31	67.41	66.92	68.03	.948
Fecal DM[c]	75.27	77.79	82.01	81.36	.893
Ileal NDF	9.42	10.89	17.48	15.11	2.541
Fecal NDF[c]	31.12	36.25	48.42	43.92	3.427
Ileal ADF[c]	12.14	19.73	21.15	26.30	2.617
Fecal ADF[c]	19.25	25.90	42.83	38.60	3.669
Ileal Cel	25.61	30.23	32.66	34.59	4.521
Fecal Cel[c]	30.12	38.33	53.88	49.53	3.253
Ileal Hem	2.75	-4.76	10.16	-5.25	5.703
Fecal Hem	51.24	55.11	58.61	53.71	5.553
Ileal Lig[c]	17.70	31.66	21.71	34.00	3.646
Fecal Lig[c]	12.70	20.69	29.79	27.08	4.440
Ileal Ash	27.48	29.19	25.79	27.70	1.830
Fecal Ash[c]	38.73	43.56	51.60	53.92	3.348

[a] Periods were 7 d duration.
[b] Standard error of the mean.
[c] Means differ within 4 wk experiment (P<.05).

However, fecal NDF digestibility did decrease (P<.07) due to elevated dietary NDF concentration. Stanogias and Pearce (1985a) reported similar results using different types and dietary concentrations of fiber. No differences (P>.05) were noted for the ileal and fecal digestibility measures of NDF with respect to dietary CP content.

Ileal and fecal measures of ADF, cellulose and ash digestibility decreased (P<.05) when dietary NDF concentration was increased from 10.8 to 23.2%. Fernandez and Jorgensen (1986) reported similar results to increasing dietary NDF stating that the digestibility of nutrients consistently decreases with increasing dietary fiber content. These results are contrary to the results of experiment 2 in which digestibilities improved with increasing dietary CF content. However, a different array of fiber (soybean meal-sunflower meal mixture vs sunflower meal) was used in this experiment which may explain some differences noted between the experiments. Fernandez and Jorgensen (1986) summarized reports of the digestibility of various fiber types and their impact on dietary component digestibilities and reported differences in digestibility due to type of fiber fed.

Dietary CP content influenced fecal digestibility of ADF (P<.09) and cellulose (P<.08) while ileal ash digestibility improved (P<.02) with increasing dietary CP. These results are similar to those of experiment 1 in which ADF, cellulose and ash digestibilities improved with increasing dietary CP. No explanation can be provided for the improvement in digestibility other than the possibility of a more optimum media for the hindgut microbes. Thus, greater hindgut microbial

activity could occur.

Ileal hemicellulose digestibility was negative when measured in pigs consuming the low NDF diet and was lower ($P<.0001$) than the digestibility of NDF in pigs fed the high NDF diet. It is interesting to note that all negative digestibilities throughout all three experiments have occurred in low fiber diets. It would appear that diet composition certainly plays a role in the factor responsible for the erroneous digestibility coefficients.

No differences ($P>.05$) were noted for fecal hemicellulose or ileal or fecal lignin digestibilities due to dietary NDF concentration. Also, no response ($P>.05$) due to dietary CP was noted for ileal or fecal hemicellulose and lignin digestibility.

It is interesting to note the improvement in digestibility of certain dietary components over time. Fecal DM, NDF, ADF, cellulose, lignin and ash all increased ($P<.05$) as the experiment progressed from start to finish. Ileal ADF and lignin digestibilities also increased with time ($P<.05$). It would appear that during this experiment the intestinal microflora is developing the capacity for increased hindgut digestion. This may explain variation between results of others who have reported results from older pigs with flourishing hindgut microflora and our experiments with young weaned pigs. It also brings to question the point of time (age) which it becomes important to measure digestibility at the ileum. If hindgut digestion of nutrients does not play a major role until a certain time there is no need for measurement at the terminal ileum. This is in agreement with Walker et al. (1986b) who

studied ileal and fecal digestibilities of protein sources using the young weaned pig and found little difference in digestibility between the two measures. Pigs used by Walker et al. (1986b) were similar in age (approximately 30 d) to pigs used in our experiments.

In conclusion, it appears that the young pig certainly has the capacity for limited fiber digestibility. The depression in DM digestibility with increased dietary fiber is a concern and dietary fiber concentrations should be narrowed to find an optimum level of NDF so as to not adversely affect DM digestibility. However, DM digestibility was not depressed in diets containing up to 8.3% CF (24.5% NDF) in experiment 2. There does appear to be some utilization of NDF by the young pig and the digestibility, contrary to other reports, improves with increasing dietary NDF. This may be influenced by the type of fiber used in experimental diets. In experiment 3, CP had essentially no effect on DM or fiber fraction digestibilities. It would appear, judging from the results of experiments 1 and 3, that dietary CP can be decreased with proper amino acid supplementation to levels below recommended concentrations (at least 17.2%) for the young weaned pig without adversely affecting digestibilities of the dietary components measured here.

Effects of Dietary Crude Protein and Fiber Content on the Digestibility of Nitrogen and Amino Acids in Diets for Young Weaned Pigs
Experiment 1

Ileal and fecal nitrogen and amino acid digestibility coefficients for pigs fed diets varying in CP content are summarized in tables 18 and 19, respectively.

Both ileal ($P<.0002$) and fecal ($P<.004$) nitrogen digestibilities differed in response to increasing dietary CP content. Nitrogen digestibility measured at the terminal ileum increased ($P<.05$) linearly due to increasing dietary CP. Nitrogen digestibilities have been reported to improve with increasing dietary CP (Armstrong and Mitchell, 1955; Sauer et al., 1980). Also, fecal nitrogen digestibility was greater than ileal measures indicating microbial digestion of remaining nitrogenous compounds. Sauer and Ozimek (1986) reported an average difference between ileal and fecal nitrogen digestibilities to be approximately 6.5%. Our average for this experiment is approximately 5.3%. The variation between the two may be explained by considering the amount of microbial digestion occurring between the more mature pigs used by Sauer and Ozimek (1986) and our young weaned pigs.

In general, ileal amino acid digestibilities improved due to increasing dietary CP. Ileal digestibilities of leucine and aspartic acid increased in a linear ($P<.05$) fashion while glutamic acid, glycine, serine and tyrosine responded linearly ($P<.05$) and quadratically ($P<.05$). Isoleucine, phenylalanine, threonine, valine and alanine digestibilities all differed ($P<.05$) due to dietary treatment.

It is interesting to note that lysine digestibility did not

TABLE 18. ILEAL NITROGEN AND AMINO ACID DIGESTIBILITY COEFFICIENTS OF PIGS FED DIETS OF VARIOUS CRUDE PROTEIN CONTENT (EXP. 1)

	Treatment				
	1	2	3		
Dietary crude protein, %	12.8	17.2	20.8		
Dietary crude fiber, %	8.2	8.5	8.6	(P<)	SE[a]
Nitrogen[d]	68.77[c]	72.75[b]	75.37[b]	.0002	1.12
Amino acids					
Indispensable					
Arginine	88.27	88.89	88.96		1.089
Histidine	70.17	73.19	79.58		3.557
Isoleucine	71.85[c]	81.16[b]	79.54[b]	.06	2.671
Leucine[d]	71.15[c]	78.93[b]	79.12[b]	.009	1.830
Lysine	69.33	67.22	68.44		3.399
Phenylalanine	79.72[c]	86.95[b]	86.96[b]	.01	1.820
Threonine	72.50[c]	72.50[c]	76.93[b]	.04	1.373
Valine	74.61[c]	81.26[b]	82.79[b]	.02	1.719
Dispensable					
Alanine	68.31[c]	74.32[b]	74.56[b]	.01	1.433
Aspartic acid[d]	77.06[c]	81.33[b]	80.53[b]	.03	1.037
Glutamic acid[de]	85.06[b]	78.52[c]	86.05[b]	.0002	.922
Glycine[de]	68.55[b]	59.08[c]	69.08[b]	.0002	1.374
Serine[de]	74.42[b]	69.53[c]	76.91[b]	.01	1.222
Tyrosine[de]	57.19[c]	87.44[b]	85.32[b]	.001	4.880

[a] Standard error of the mean.
[bc] Means within the same row with uncommon superscripts differ.
[d] Linear response (P<.05).
[e] Quadratic response (P<.05).

TABLE 19. FECAL NITROGEN AND AMINO ACID DIGESTIBILITY COEFFICIENTS OF PIGS FED DIETS OF VARIOUS CRUDE PROTEIN CONTENT (EXP. 1)

	Treatment				
	1	2	3		
Dietary crude protein, %	12.8	17.2	20.8		
Dietary crude fiber, %	8.2	8.5	8.6	(P<)	SE[a]
Nitrogen	74.99[c]	76.72[c]	80.98[b]	.004	.875
Amino acids					
Indispensable					
Arginine	92.85[c]	92.64[c]	95.77[b]	.02	.725
Histidine[e]	79.57[c]	87.82[c]	86.75[b]	.02	1.777
Isoleucine	72.27	77.89	81.94		3.266
Leucine	77.26[c]	81.72[b]	83.11[b]	.05	1.392
Lysine	76.14[c]	80.89[c]	88.34[b]	.001	1.922
Phenylalanine	80.57	86.44	88.44	.05	1.835
Threonine[ef]	75.05[c]	71.56[c]	80.89[b]	.05	1.713
Valine	75.83[c]	82.18[b]	85.63[b]	.03	1.840
Dispensable					
Alanine	71.91[c]	75.58[b]	80.14[b]	.06	2.243
Aspartic acid	78.25[c]	84.36[b]	87.04[b]	.009	1.354
Glutamic acid[ef]	89.79[c]	84.09[d]	94.18[b]	.009	.913
Glycine[ef]	82.16[b]	75.02[c]	84.62[b]	.0001	1.045
Serine[ef]	81.66[c]	76.23[d]	86.35[b]	.01	1.035
Tyrosine[e]	44.76[c]	77.81[b]	81.85[b]	.002	5.916

[a] Standard error of the mean.
[bcd] Means within the same row with uncommon superscripts differ.
[e] Linear response (P<.05).
[f] Quadratic response (P<.05).

vary (P<.05) across treatments. This may be caused by the supplementation of L-lysine HCL to the diets to maintain equal dietary lysine content. Supplementation of the crystalline lysine was greatest for diet 1 and least for diet 3. The digestibilities we would expect without this addition (judging by the pattern of other amino acid digestibilities in this experiment) would be lowest for diet 1 and greatest for diet 3. However, crystalline or "free" amino acids are assumed to be 100% digestible, thus masking any obvious differences in digestibility across treatments.

Threonine and isoleucine were also supplemented to the low protein diets in a free form of the amino acids. However, apparent isoleucine digestibility does not appear to have been enhanced by the readily digestible free form of the isoleucine. Pigs fed diet 1, which contained crystalline L-isoleucine, had the lowest isoleucine digestibilities.

Glycine digestibilities were somewhat lower than the average of the other amino acids. This may be explained by the fact that glycine is a part of the bile salt hyocholic acid. Thus, when estimating apparent glycine digestibility the value appears to be low due to endogenous contribution of glycine (Low, 1979). Other amino acids suggested to be affected by endogenous secretions are aspartic acid, serine, threonine and alanine, all part of porcine pancreatic juice. Also, porcine intestinal mucus was reported to contain significant quantities of threonine (Low, 1979). Endogenous flow has been reported by Low to be constant across a wide range of CP intake.

The large variation in tyrosine digestibility may be exagerated between pigs fed diet 1 and diet 2 because of variation in tyrosine analysis. Digesta samples contained small amounts of tyrosine and integration of the tyrosine peak, especially of the low protein samples, was difficult. Thus, the large difference in tyrosine digestibility may be due more to variation in analysis than in reponse to a low protein diet.

Sauer et al. (1980) suggested that improved nitrogen and amino acid digestibility with increased dietary CP is due to increased endogenous secretion. They stated that endogenous secretions are proportional to DM intake so that at lower dietary CP concentrations the endogenous nitrogen accounts for a larger proportion of the nitrogen measured. Thus, at equal DM intake apparent nitrogen digestibilities of lower CP diets would be depressed more than those of high CP diets.

The fact that amino acid digestibility is greater than nitrogen digestibility has been explained by Sauer et al. (1980). They reported the difference to be due to CP containing lower nitrogen compounds, which are less digestible. Therefore, total nitrogen digestibility coefficients are less than coefficients for amino acids which are only a portion of the total dietary nitrogen.

Fecal amino acid digestibilities all differed ($P<.05$) due to dietary CP content with the exception of isoleucine which increased numerically but not statistically ($P>.05$). Fecal isoleucine digestibility is similar to ileal digestibilities and is slightly less

than ileal measures for pigs fed diet 2. This indicates a net synthesis of isoleucine between the ileum and the feces. Low (1979) reported increased relative concentration of isoleucine, due to microbial activity in the hindgut, when comparing ileal digesta and feces. This explains a lower apparent fecal digestibility of isoleucine which compares closely with ileal digestibility measures of isoleucine. Similar effects can be noted with the relatively close ileal and fecal digestibility coefficients of phenylalanine, threonine, valine and tyrosine.

Fecal histidine and tyrosine digestibilities improved linearly ($P<.05$) while threonine, glutamic acid, glycine and serine responded linearly ($P<.05$) and quadratically ($P<.05$) to increasing dietary CP. It is interesting to note that glycine digestibility, which at the ileum was much lower than the average ileal amino acid digestibility is within the "normal" range of digestibility when measured in the feces, indicating significant hindgut microbial activity.

The general increase in amino acid digestibility over increasing dietary CP level has been reported by Just (1979) who fed growing pigs diets containing 17, 24 and 33% CP and noted improved amino acid digestibilities.

In this experiment, it would appear that all indispensable amino acid digestibilities are maximized at 17.2% dietary CP, except threonine which continued to increase ($P<.04$) to the 20.8% dietary CP content. Also, the ileal digestibilities of the dispensable amino acids alanine, aspartic acid and tyrosine were maximized at 17.2% dietary CP

whereas glutamic acid, glycine and serine continued to increase in digestibility to 20.8% dietary CP.

Differences between ileal and fecal nitrogen and amino acid digestibilities suggest the need for studying amino acid digestibilities at the terminal ileum for a more accurate measure. This is in contrast to the report of Walker et al. (1986b) who suggested fecal amino acid digestibility measures to be as accurate as ileal measures. However, they fed young weaned pigs, similar in age and weight to ours, highly digestible diets. Diet composition may have played a role in the variation between the two experiments.

Experiment 2

Ileal and fecal digestibility coefficients for nitrogen and amino acids of pigs fed diets varying in CF content are summarized in tables 20 and 21, respectively.

Although ileal and fecal nitrogen digestibility coefficients decreased approximately 4 and 2%, respectively, no statistical difference ($P>.05$) occurred due to increasing dietary CF content. Depression of CP digestibility, both at the ileum and over the entire digestive tract of growing-finishing pigs due to elevated dietary fiber has been reported (Just, 1979; Sauer et al., 1980; Sauer and Ozimek, 1986). Walker et al. (1986b) fed young weaned pigs (approximately 30 d old) highly digestible diets (casein, isolated soy protein, ethanol extracted soy protein) and reported depressed ileal and fecal digestibility of nitrogen when pigs were fed a soybean meal based diet of greater CF content.

TABLE 20. ILEAL NITROGEN AND AMINO ACID DIGESTIBILITY COEFFICIENTS OF PIGS FED DIETS OF VARIOUS CRUDE FIBER CONTENT (EXP. 2)

	Treatment				
	1	2	3		
Dietary crude protein, %	20.9	20.8	21.0		
Dietary crude fiber, %	5.4	8.3	11.7	(P<)	SE[a]
Nitrogen	70.97	69.61	66.98		2.203
Amino acids					
Indispensable					
Arginine[ef]	84.26[c]	89.28[b]	81.56[c]	.01	1.306
Histidine[ef]	71.30[c]	77.87[b]	68.61[c]	.006	1.444
Isoleucine	75.37[b]	71.61[bc]	66.84[c]	.007	1.929
Leucine	74.13[b]	71.64[bc]	67.94[c]	.009	1.445
Lysine[ef]	69.67[c]	75.45[b]	63.26[d]	.03	1.773
Phenylalanine	81.11[b]	79.41[b]	74.36[c]	.04	1.615
Threonine[ef]	63.86[bc]	67.05[b]	59.93[c]	.01	1.808
Valine	72.19[b]	69.28[b]	59.35[c]	.005	2.155
Dispensable					
Alanine	64.69	59.62	58.77		2.822
Aspartic acid[ef]	69.37[b]	72.53[b]	63.04[c]	.008	1.468
Glutamic acid[f]	78.97[b]	80.22[b]	74.61[c]	.03	1.335
Glycine	60.59	62.12	55.60		2.405
Serine	66.69	68.68	64.70		1.607
Tyrosine	80.37	81.10	77.23		3.706

[a] Standard error of the mean.
[bcd] Means within the same row with uncommon superscripts differ.
[e] Linear response (P<.05).
[f] Quadratic response (P<.05).

TABLE 21. FECAL NITROGEN AND AMINO ACID DIGESTIBILITY COEFFICIENTS OF PIGS FED DIETS OF VARIOUS CRUDE FIBER CONTENT (EXP. 2)

	Treatment				
	1	2	3		
Dietary crude protein, %	20.9	20.8	21.0		
Dietary crude fiber, %	5.4	8.3	11.7	(P<)	SE[a]
Nitrogen	78.30	76.42	76.35		1.853
Amino acids					
Indispensable					
Arginine	89.68	89.36	87.47		.768
Histidine	83.39	83.54	81.89		1.149
Isoleucine	73.48	68.88	68.44		1.999
Leucine	76.73	74.50	73.63		1.501
Lysine	77.86[b]	75.58[b]	70.99[c]	.04	1.495
Phenylalanine	80.40	79.61	78.38		1.465
Threonine	70.02	72.35	67.40		1.742
Valine	75.40[b]	72.06[b]	63.34[c]	.02	2.436
Dispensable					
Alanine	69.24	66.93	63.60		1.993
Aspartic acid	76.27	76.85	72.09		1.572
Glutamic acid	86.81	86.82	85.16		.829
Glycine	79.25	78.81	77.23		1.571
Serine	78.02	78.30	75.89		1.266
Tyrosine	64.43	73.29	73.44		3.908

[a] Standard error of the mean.
[bc] Means within the same row with uncommon superscripts differ.

Fecal nitrogen output, which would certainly influence apparent fecal nitrogen digestibility has been reported to be affected by the type and amount of carbohydrate presented to the microflora of the large intestine. Mosenthin et al. (1986) and Misir and Sauer (1982) reported increased fecal nitrogen output when starch or other fermentable carbohydrates were infused into the cecum. They reported that a large portion of the nitrogen output was of microbial origin thus largely influencing apparent nitrogen digestibility estimates. Misir and Sauer (1982) suggested that increased bacterial protein synthesis, using gut ammonia originating from the breakdown of dietary CP, decreased the amount of gut ammonia absorbed and eventually excreted in the urine so that total nitrogen balance remained equal. This may explain the less drastic decrease in fecal nitrogen digestibility as CF increases from 5.4 to 8.3% as compared to ileal digestibility differences between similar diets.

In general, amino acid digestibilities declined with increasing dietary CF content. Ileal arginine, histidine, lysine, threonine, aspartic acid and glutamic acid digestibilities responded quadratically ($P<.05$) to CF content with the highest digestibility coefficients in pigs fed diet 2 (8.3% CF). Diet composition of diet 2 is such that a relatively high fiber, low protein sunflower meal is mixed with a relatively low fiber, high protein sunflower meal. Diet 1 is composed of only one sunflower meal. However, fiber in all diets is supplied by sunflower meal and CF and NDF levels in diet 2 are intermediate to diets 1 and 3. Therefore no explanation can be provided for the elevated

ileal amino acid digestibilities when pigs were fed diet 2.

Glycine, serine, alanine, aspartic acid and threonine digestibilities were lowest among the ileal digestibility coefficients again supporting the reports that these amino acids are secreted into the small intestine as porcine pancreatic juice, hyocholic acid and porcine intestinal mucus (Low, 1979).

Fecal amino acid digestibility did not differ ($P<.05$) due to various dietary CF content other than depression of lysine ($P<.04$) and valine ($P<.02$) digestibilities which occurred with increasing dietary CF. The quadratic digestibility effect noted with many of the amino acids at the ileum was not evident when measured at the feces. Only small differences were noted between fecal and ileal digestibilities of isoleucine, phenylalanine and valine due to microbial contribution of these amino acids in the hindgut thus depressing apparent fecal digestibilities (Low, 1979). Fecal tyrosine digestibility was up to 16% less than ileal measures. Low (1979) reported increased tyrosine concentration in the feces of 30 kg pigs and suggested it was due to microbial activity. Sauer and Ozimek (1986) reported that when feeding elevated fiber diets bacterial amino acid contribution to the feces would increase due to the physical nature of the digesta progressing down the large intestine. Because greater numbers of bacteria in the feces would increase relative amino acid concentration in the feces digestibilities would appear to be low. Therefore, this supports the relatively small differences between the digestibilities of some amino acids when comparing ileal and fecal estimates.

In this experiment, fecal digestibility of nearly all of the amino acids remained similar until pigs were fed the 11.7% CF diet. The exception to this were those amino acids that responded quadratically at the intermediate CF concentration. Thus, it would appear that the young weaned pig can tolerate elevated (8.3%) levels of CF without adversely affecting nitrogen and amino acid digestibilities.

Experiment 3

Ileal and fecal nitrogen and amino acid digestibility coefficients are summarized in tables 22 and 23, respectively. Coefficients for ileal and fecal nitrogen digestibilities over time are provided in tables 24 and 25, respectively.

Data were analyzed to test for the NDF*CP interaction. For some estimates of amino acid digestibility there were significant ($P<.05$) interactions so individual treatment means are presented.

Ileal nitrogen digestibility was affected by dietary CP content ($P<.03$) but not dietary NDF concentration ($P>.05$). Digestibility of nitrogen measured at the terminal ileum improved as dietary CP increased from approximately 18.6 to approximately 24.1%. This response is in agreement with the results of experiment 1 and also with experiments using older pigs (50 to 70 kg) reported by Sauer et al. (1980) and Sauer and Ozimek (1986). Also, in agreement with these results are those of experiment 2 where no depression in nitrogen digestibility occurred with increased dietary CF content. Dietary CF content of the experimental diets in experiment 3 were approximately 3.8 and 9.6% for low and high fiber diets, respectively.

TABLE 22. ILEAL NITROGEN AND AMINO ACID DIGESTIBILITY COEFFICIENTS OF YOUNG WEANED PIGS (EXP. 3)

	Treatment					
	1	2	3	4		
Dietary crude protein,%	18.7	18.6	24.4	24.1		
Dietary NDF,%	10.8	23.2	10.8	22.8	(P<)	SE[a]
Nitrogen[e]	70.59[c]	69.41[c]	74.34[b]	74.38[b]	.03	1.150
Amino acids						
Indispensable						
Arginine[f]	83.93	85.44	86.62	84.37		.825
Histidine[de]	74.57[c]	73.55[c]	80.40[b]	73.85[c]	.01	1.504
Isoleucine	77.11	79.96	79.30	77.75		1.603
Leucine	76.19	75.88	76.80	77.30		1.326
Lysine[d]	74.97[b]	72.80[bc]	76.91[b]	69.59[c]	.05	1.837
Phenylalanine	75.53	80.03	78.28	77.62		1.768
Threonine[d]	76.88	73.94	77.22	73.75		1.319
Valine	79.93	80.57	80.71	79.08		1.405
Dispensable						
Alanine	76.71	74.30	74.57	77.55		1.554
Aspartic acid	79.12	76.40	78.68	77.31		1.199
Glutamic acid	85.14	84.09	83.18	84.56		.861
Glycine[d]	68.66[b]	60.14[c]	70.33[b]	59.94[c]	.0001	1.194
Serine[df]	77.69[b]	71.52[c]	76.09[b]	76.37[b]	.01	1.338
Tyrosine	55.62	59.03	73.84	75.63		6.798

[a] [bc] Standard error of the mean.
Means within the same row with uncommon superscripts differ.
[d] Neutral detergent fiber response (P<.05).
[e] Crude protein response (P<.05).
[f] NDF * CP (P<.05).

TABLE 23. FECAL NITROGEN AND AMINO ACID DIGESTIBILITY COEFFICIENTS OF YOUNG WEANED PIGS (EXP. 3)

	Treatment					
	1	2	3	4		
Dietary crude protein, %	18.7	18.6	24.4	24.1		
Dietary NDF, %	10.8	23.2	10.8	22.8	(P<)	SE[a]
Nitrogen[fg]	79.29[c]	70.37[e]	83.16[b]	76.42[d]	.04	.995
Amino acids						
Indispensable						
Arginine[fh]	86.17[c]	85.78[c]	90.16[b]	85.58[c]	.006	.974
Histidine[fgh]	81.38[c]	78.62[c]	88.58[b]	79.37[c]	.0007	1.344
Isoleucine[fh]	74.90[c]	72.07[c]	79.60[b]	70.89[c]	.03	1.467
Leucine[f]	78.66[bc]	75.10[d]	80.89[b]	76.92[cd]	.02	1.042
Lysine[f]	81.53[b]	73.43[c]	82.88[b]	69.66[c]	.0002	1.364
Phenylalanine[fh]	76.70[c]	76.32[c]	82.08[b]	74.70[c]	.006	1.286
Threonine[f]	79.77[b]	72.39[c]	81.76[b]	70.09[c]	.0001	1.174
Valine[fh]	80.80[bc]	77.46[cd]	83.57[b]	74.59[d]	.02	1.277
Dispensable						
Alanine[f]	79.36[b]	71.86[d]	78.40[b]	74.91[c]	.05	1.054
Aspartic acid[f]	84.64[b]	79.27[c]	86.46[b]	78.47[c]	.0001	.842
Glutamic acid[f]	90.32[b]	86.99[c]	90.84[b]	87.14[c]	.0001	.516
Glycine[f]	81.48[b]	71.79[c]	82.98[b]	72.35[c]	.0001	.872
Serine[fg]	84.79[b]	76.69[d]	85.34[b]	79.80[c]	.0004	.723
Tyrosine[g]	37.65[c]	41.12[c]	73.03[b]	63.09[b]	.0001	3.697

[a] Standard error of the mean.
[bcde] Means within the same row with uncommon superscripts differ.
[f] Neutral detergent fiber response (P<.05).
[g] Crude protein response (P<.05).
[h] NDF * CP.

TABLE 24. EFFECT OF TIME ON ILEAL NITROGEN AND AMINO ACID DIGESTIBILITIES OF YOUNG WEANED PIGS (EXP. 3)

	Period[a]				
	1	2	3	4	SE[b]
Nitrogen	70.63	73.44	71.42	73.23	1.150
Amino acids					
Indispensable					
Arginine	85.74	85.30	84.33	84.99	.825
Histidine	75.36	75.55	73.86	77.61	1.504
Isoleucine	78.47	80.34	78.37	76.94	1.603
Leucine	76.37	78.09	75.95	75.74	1.326
Lysine	73.11	75.80	71.62	73.73	1.837
Phenylalanine	78.06	78.37	77.59	77.44	1.768
Threonine	75.96	76.24	74.97	74.62	1.319
Valine	79.30	82.34	81.06	77.58	1.405
Dispensable					
Alanine	75.37	77.94	75.55	74.27	1.554
Aspartic acid	79.11	79.11	76.98	76.31	1.199
Glutamic acid	85.19	85.41	83.91	82.48	.861
Glycine	65.40	66.66	62.12	64.91	1.194
Serine	76.76	76.43	74.09	74.40	1.338
Tyrosine	66.88	67.66	70.86	58.73	6.798

[a] Periods were 7 d duration.
[b] Standard error of the mean.

TABLE 25. EFFECT OF TIME ON FECAL NITROGEN AND AMINO ACID DIGESTIBILITIES OF YOUNG WEANED PIGS (EXP. 3)

	Period[a]				
	1	2	3	4	SE[b]
Nitrogen[c]	70.91	76.67	80.69	80.97	.995
Amino acids					
Indispensable					
Arginine[c]	81.41	86.47	89.38	90.44	.974
Histidine[c]	73.46	80.98	85.29	88.23	1.344
Isoleucine[c]	65.73	75.39	77.76	78.58	1.467
Lysine[c]	71.46	78.18	80.58	81.36	1.024
Lysine[c]	67.78	73.82	80.81	85.10	1.364
Phenylalanine[c]	68.55	78.45	81.09	81.71	1.286
Threonine[c]	70.77	75.66	78.33	79.25	1.174
Valine[c]	74.29	79.58	80.46	82.08	1.277
Dispensable					
Alanine[c]	70.78	76.59	77.56	79.60	1.054
Aspartic acid[c]	78.40	82.06	83.79	84.59	.842
Glutamic acid[c]	87.10	88.49	89.68	90.02	.516
Glycine[c]	70.24	75.52	80.72	82.12	.872
Serine[c]	78.99	80.83	83.23	83.57	.723
Tyrosine[c]	31.16	63.87	61.25	58.59	3.697

[a] Periods were 7 d duration.
[b] Standard error of the mean.
[c] Means differ within 4 wk experiment ($P<.05$).

Fecal nitrogen digestibility responded to both dietary CP and NDF by improving (P<.04) with increased dietary CP and decreasing (P<.04) with increased dietary NDF content. These results partially agree with the results of our previous experiments in that fecal nitrogen digestibility improved with increasing dietary CP in experiment 1 but in experiment 2 there was no response to dietary CF on fecal nitrogen digestibility. Also in agreement with these results are those of Armstrong and Mitchell (1955) and Sauer et al. (1980). They reported improved fecal nitrogen digestibility when pigs 25 and 50 kg, respectively, were fed diets of higher CP content. The decline in fecal nitrogen digestibility caused by elevated dietary NDF is also well supported (Just, 1979; Sauer and Ozimek, 1986; Den Hartog et al., 1988). True nitrogen digestibility (excluding endogenous and bacterial nitrogen contribution) is most likely not altered. However, due to a greater bacterial nitrogen contribution when high fiber diets are fed (Sauer and Ozimek, 1986) apparent digestibility is depressed.

Ileal digestibility of histidine, lysine, threonine, glycine and serine decreased (P<.05) due to dietary NDF content. Histidine digestibility at the terminal ileum also responded (P<.05) to dietary CP content with improved digestibility. There was an NDF*CP interaction for ileal arginine and serine digestion. The depression in amino acid digestibility at the ileum by dietary NDF is in agreement with the results of Just (1979) and Sauer et al. (1980). Improvement in amino acid digestibility due to increased dietary CP has also been reported (Sauer et al., 1980; Sauer and Ozimek, 1986).

The ileal glycine digestibility coefficient was the lowest of the digestibility coefficients measured and over the four dietary treatments seemed to be lowest when pigs were fed diets with elevated dietary NDF content. Glycine digestibility has been reported to be depressed at the ileum because of endogenous glycine (Low, 1979). It appears that the effect is more pronounced on high fiber diets possibly suggesting an enhanced flow of endogenous material at higher levels of NDF. Taverner et al. (1981) reported endogenous secretions increased linearly with increasing dietary NDF. This would support the hypothesis of more severely depressed apparent glycine digestibility at higher dietary NDF content.

Dietary CP and NDF had more of an impact on the fecal measures of amino acid digestibility than those at the ileum. Digestibility of every amino acid studied, except tyrosine, responded to increased dietary NDF content with a depression ($P<.05$) in digestibility. Taverner and Farrell (1981b) reported high negative correlations between dietary NDF and amino acid digestibilities. Dietary CP content affected fecal serine, histidine and tyrosine digestibility such that increasing dietary CP improved ($P<.05$) amino acid digestibility. This is in agreement with the results of experiment 1 and also with reports of Just (1979) and Sauer et al. (1980).

Interactions ($P<.05$) of dietary NDF*CP occurred for arginine, histidine, isoleucine, phenylalanine and valine. For each amino acid reduction in digestibility occurred due to dietary NDF but was more severe at higher dietary CP content thus causing the interaction. This

appears to be caused by enhanced microbial growth in the hindgut. An increased amount of bacteria in the feces would increase levels of arginine, histidine, isoleucine, phenylalanine and valine so as to decrease apparent digestibility estimates.

A number of the amino acids were apparently more completely digested at the ileum than when measured in the feces. Tyrosine digestibility was greater at the ileum than fecal measures for all diets fed but the greatest difference between ileal and fecal digestibilities were at low dietary CP content. Fecal digestibilities of isoleucine, phenylalanine, threonine, alanine and aspartic acid were lower than ileal digestibilities at higher dietary NDF content. Low (1979) reported similar results of increasing amounts of these amino acids when sampling at the ileum and feces of growing pigs. Low attributed the increase to significant hindgut microbial activity. That the digestibilities are greater on the higher dietary NDF concentration is understandable because of the possible enhancement of microbial activity with increased fermentable carbohydrate presented to the large intestinal microbes (Mosenthin et al., 1986).

There was an interesting effect due to time with respect to nitrogen and amino acid digestibility. No differences ($P<.05$) in nitrogen or amino acid digestibilities were noted over the 4 wk period when digestibilities were measured at the ileum. However, when studying nitrogen and amino acid digestibility over the entire digestive tract there is a steady improvement in digestibility over time. This would certainly suggest that at the beginning of our experiment intestinal

microflora are not well established but continue to proliferate as time passes. This has important implications in the time when ileal vs fecal measurement of nitrogen and amino acids is required for accurate digestibility estimates. At the beginning of the experiment (period 1) digestibilities of nearly all the amino acids are greater when measured at the ileum. As the experiment progressed fecal digestibilities slowly surpass ileal measures at equal time. Although this experiment is unable to define a time period where ileal measurement is required for accurate amino acid digestibility estimates it would appear that a three week old weaned pig may not have a significant intestinal microflora.

In conclusion, it appears that ileal nitrogen and amino acid digestibility is relatively constant across various dietary fiber and CP content. In experiment 2, CF levels of 8.3% (24.5% NDF) did not significantly reduce digestibilities and very few of the amino acids studied had depressed digestibilities due to increasing dietary NDF from 10.8 to 23.2% in experiment 3. Crude protein content does not appear to limit amino acid digestibilities at reduced concentrations (17.2%, exp. 1) nor stimulate digestibilities at elevated (24.1%) levels as in experiment 3. Thus, data suggest that use of dietary fiber for its possible beneficial aspects is possible assuming adequate metabolizable energy is available. In these experiments increasing dietary CP content provided only limited benefit to nitrogen and essentially no benefit to amino acid digestibility when measured at the ileum.

It would appear from these experiments that making estimates of nitrogen and amino acid digestibilities at the ileum is important and that fecal estimates would most likely overestimate apparent digestibility. There is however a definite variation due to diet composition that must be considered when applying fecal digestibility measures to apparent digestibility. Also, there seems to be a time, in this experiment the first two weeks, where fecal estimates of amino acid digestibility would seem to be nearly as accurate as ileal digestibility measures.

SUMMARY

Three experiments were conducted with the objectives of studying the effects of dietary CP and fiber on the digestibilities of various dietary components in diets fed to the young weaned pig.

In experiment 1, increasing the dietary CP content improved ($P<.05$) digestibilities of NDF, ADF, CF, cellulose, hemicellulose and lignin both at the terminal ileum and over the entire digestive tract. Digestibility of ileal ash, nitrogen, and most amino acids improved ($P<.03$) while ileal and fecal DM digestibilities decreased to 17.2% dietary CP then plateaued. Results from this experiment suggest increasing CP above 17.2% provides relatively no benefit to dietary component digestibilities.

In experiment 2, increasing dietary NDF from 20.5 to 30.5% depressed ($P<.04$) ileal DM digestibility but improved ($P<.04$) measures of ADF, CF, cellulose and lignin digestibility. Dietary NDF content did not affect ($P>.05$) ileal or fecal nitrogen digestibilities but tended to depress amino acid digestibilities ($P<.05$) when dietary NDF was increased from 20.5 to 30.5%. For all digestibility measures studied a plateau seemed to occur at approximately 24.5% dietary NDF.

In experiment 3, increasing dietary NDF depressed ($P<.05$) ileal and fecal measures of DM, ADF, cellulose, ash, ileal hemicellulose and fecal NDF and nitrogen digestibility. Digestibilities of histidine, lysine, glycine and serine were depressed ($P<.05$) when measured at the ileum due to dietary NDF but many (arginine, histidine, isoleucine, leucine, lysine, phenylalanine, threonine, valine, serine and tyrosine)

were depressed (P<.05) when fecal amino acid digestibility was studied. Increasing dietary CP content improved (P<.04) ileal and fecal nitrogen, ileal histidine and most fecal amino acid measurements.

There was an interesting effect due to time in that fecal digestibilities of dietary fractions (dry matter, nitrogen, all amino acids, NDF, ADF, cellulose, lignin and ash) improved with time as experiment 3 progressed. However, the same effect was not noted when digestibilities were measured at the ileum. This effect is most likely due to an increase in the microbial population of the large intestine.

Results of these experiments suggest that the young weaned pig is able to make limited use of dietary fiber. There appears to be a depression in dietary component digestibilities beyond approximately 24.5% dietary NDF. However, results of experiment 2 and 3 suggest source of dietary fiber may play a role in its effects on component digestibilities. Also, dietary CP content appears to affect diet digestibility, especially at low concentration (12.8%). Results suggest, however, that dietary CP may be able to be decreased below recommended dietary CP content for the young weaned pig without adversely affecting dietary component digestibilities. Also, improvements in various dietary component digestibilities over time suggests the hindgut of the young weaned pig and its inherent microbes are not fully functional at this young age. This brings to question the time period of which it becomes important to use cannulated pigs for estimates of apparent digestibility.

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TABLE 1. ANALYSIS OF VARIANCE FOR FECAL NITROGEN DIGESTIBILITY (EXP. 1)

	Overall analysis of variance		Polynomial regression	
Source	df	Mean Square	df	Mean Square
Total	26	16.833	26	16.833
Pig	8	19.179	8	19.179
Period	2	8.375	2	8.375
Treatment	2	85.540	-	-
Linear	-	-	1	1.573
Quadratic	-	-	1	9.618
Error	14	6.886	14	6.886

TABLE 2. ANALYSIS OF VARIANCE FOR FECAL DRY MATTER DIGESTIBILITY (EXP. 1)

	Overall analysis of variance		Polynomial regression	
Source	df	Mean Square	df	Mean Square
Total	26	2.494	26	2.494
Pig	8	3.725	8	3.725
Period	2	2.133	2	2.133
Treatment	2	4.749	-	-
Linear	-	-	1	7.856
Quadratic	-	-	1	6.713
Error	14	1.521	14	1.521

TABLE 3. ANALYSIS OF VARIANCE FOR FECAL NEUTRAL DETERGENT FIBER DIGESTIBILITY (EXP. 1)

	Overall analysis of variance		Polynomial regression	
Source	df	Mean Square	df	Mean square
Total	26	164.394	26	164.394
Pig	8	40.824	8	40.824
Period	2	25.977	2	25.977
Treatment	2	1688.581	-	-
Linear	-	-	1	82.904
Quadratic	-	-	1	.660
Error	14	37.038	14	37.038

TABLE 4. ANALYSIS OF VARIANCE FOR FECAL ACID DETERGENT FIBER DIGESTIBILITY (EXP. 1)

	Overall analysis of variance		Polynomial regression	
Source	df	Mean Square	df	Mean Square
Total	26	198.055	26	198.055
Pig	8	53.790	8	53.790
Period	2	5.388	2	5.388
Treatment	2	2154.047	-	-
Linear	-	-	1	86.286
Quadratic	-	-	1	.008
Error	14	27.875	14	27.875

TABLE 5. ANALYSIS OF VARIANCE FOR FECAL CRUDE FIBER DIGESTIBILITY (EXP. 1)

	Overall analysis of variance		Polynomial regression	
Source	df	Mean Square	df	Mean Square
Total	26	160.632	26	160.632
Pig	8	82.889	8	82.889
Period	2	25.050	2	25.050
Treatment	2	1310.523	-	-
Linear	-	-	1	4.026
Quadratic	-	-	1	28.326
Error	14	60.155	14	60.155

TABLE 6. ANALYSIS OF VARIANCE FOR FECAL CELLULOSE DIGESTIBILITY (EXP. 1)

	Overall analysis of variance		Polynomial regression	
Source	df	Mean Square	df	Mean Square
Total	26	314.554	26	314.554
Pig	8	98.296	8	98.296
Period	2	27.168	2	27.168
Treatment	2	3395.232	-	-
Linear	-	-	1	54.571
Quadratic	-	-	1	19.476
Error	14	39.089	14	39.089

TABLE 7. ANALYSIS OF VARIANCE FOR FECAL LIGNIN DIGESTIBILITY (EXP. 1)

	Overall analysis of variance		Polynomial regression	
Source	df	Mean Square	df	Mean Square
Total	26	65.577	26	65.577
Pig	8	10.431	8	10.431
Period	2	43.227	2	43.227
Treatment	2	394.321	-	-
Linear	-	-	1	38.837
Quadratic	-	-	1	5.091
Error	14	53.318	14	53.318

TABLE 8. ANALYSIS OF VARIANCE FOR FECAL HEMICELLULOSE DIGESTIBILITY (EXP. 1)

	Overall analysis of variance		Polynomial regression	
Source	df	Mean Square	df	Mean Square
Total	26	130.904	26	130.904
Pig	8	70.644	8	70.644
Period	2	153.159	2	153.159
Treatment	2	559.772	-	-
Linear	-	-	1	66.383
Quadratic	-	-	1	11.751
Error	14	100.893	14	100.893

TABLE 9. ANALYSIS OF VARIANCE FOR FECAL ASH DIGESTIBILITY (EXP. 1)

	Overall analysis of variance		Polynomial regression	
Source	df	Mean Square	df	Mean Square
Total	26	97.771	26	97.771
Pig	8	62.283	8	62.283
Period	2	9.212	2	9.212
Treatment	2	73.760	-	-
Linear	-	-	1	145.660
Quadratic	-	-	1	147.378
Error	14	134.131	14	134.131

TABLE 10. ANALYSIS OF VARIANCE FOR ILEAL NITROGEN DIGESTIBILITY (EXP. 1)

	Overall analysis of variance		Polynomial regression	
Source	df	Mean Square	df	Mean Square
Total	26	34.354	26	34.354
Pig	8	16.052	8	16.052
Period	2	29.179	2	29.179
Treatment	2	274.198	-	-
Linear	-	-	1	94.106
Quadratic	-	-	1	42.987
Error	14	11.289	14	11.289

TABLE 11. ANALYSIS OF VARIANCE FOR ILEAL DRY MATTER DIGESTIBILITY (EXP. 1)

	Overall analysis of variance		Polynomial regression	
Source	df	Mean Square	df	Mean Square
Total	26	4.956	26	4.956
Pig	8	6.328	8	6.328
Period	2	12.447	2	12.447
Treatment	2	13.155	-	-
Linear	-	-	1	2.534
Quadratic	-	-	1	.773
Error	14	1.930	14	1.930

TABLE 12. ANALYSIS OF VARIANCE FOR ILEAL NEUTRAL DETERGENT FIBER DIGESTIBILITY (EXP. 1)

	Overall analysis of variance		Polynomial regression	
Source	df	Mean Square	df	Mean Square
Total	26	178.202	26	178.202
Pig	8	38.657	8	38.657
Period	2	57.352	2	57.352
Treatment	2	1963.216	-	-
Linear	-	-	1	28.014
Quadrati	-	-	1	13.550
Error	14	20.205	14	20.205

TABLE 13. ANALYSIS OF VARIANCE FOR ILEAL ACID DETERGENT FIBER DIGESTIBILITY (EXP. 1)

	Overall analysis of variance		Polynomial regression	
Source	df	Mean Square	df	Mean Square
Total	26	218.997	26	218.997
Pig	8	22.683	8	22.683
Period	2	16.022	2	16.022
Treatment	2	2569.429	-	-
Linear	-	-	1	83.352
Quadratic	-	-	1	1.257
Error	14	24.397	14	24.397

TABLE 14. ANALYSIS OF VARIANCE FOR ILEAL CRUDE FIBER DIGESTIBILITY (EXP. 1)

	Overall analysis of variance		Polynomial regression	
Source	df	Mean Square	df	Mean Square
Total	26	132.210	26	132.210
Pig	8	44.110	8	44.110
Period	2	81.096	2	81.096
Treatment	2	1238.571	-	-
Linear	-	-	1	4.601
Quadrat	-	-	1	85.127
Error	14	31.805	14	31.805

TABLE 15. ANALYSIS OF VARIANCE FOR ILEAL CELLULOSE DIGESTIBILITY (EXP. 1)

	Overall analysis of variance		Polynomial regression	
Source	df	Mean Square	df	Mean Square
Total	26	335.873	26	335.873
Pig	8	24.067	8	24.067
Period	2	42.106	2	42.106
Treatment	2	3893.398	-	-
Linear	-	-	1	3.030
Quadratic	-	-	1	118.400
Error	14	47.753	14	47.753

TABLE 16. ANALYSIS OF VARIANCE FOR ILEAL LIGNIN DIGESTIBILITY (EXP. 1)

	Overall analysis of variance		Polynomial regression	
Source	df	Mean Square	df	Mean Square
Total	26	37.095	26	37.095
Pig	8	41.327	8	41.327
Period	2	16.985	2	16.985
Treatment	2	207.490	-	-
Linear	-	-	1	.049
Quadratic	-	-	1	7.238
Error	14	13.207	14	13.207

TABLE 17. ANALYSIS OF VARIANCE FOR ILEAL HEMICELLULOSE DIGESTIBILITY (EXP. 1)

	Overall analysis of variance		Polynomial regression	
Source	df	Mean Square	df	Mean Square
Total	26	197.381	26	197.381
Pig	8	171.802	8	171.802
Period	2	239.286	2	239.286
Treatment	2	628.535	-	-
Linear	-	-	1	9.876
Quadratic	-	-	1	66.511
Error	14	144.418	14	144.418

TABLE 18. ANALYSIS OF VARIANCE FOR ILEAL ASH DIGESTIBILITY (EXP. 1)

	Overall analysis of variance		Polynomial regression	
Source	df	Mean Square	df	Mean Square
Total	26	80.666	26	80.666
Pig	8	21.120	8	21.120
Period	2	12.373	2	12.373
Treatment	2	518.988	-	-
Linear	-	-	1	262.401
Quadratic	-	-	1	145.304
Error	14	61.831	14	61.831

TABLE 19. ANALYSIS OF VARIANCE FOR ILEAL ASPARTIC ACID DIGESTIBILITY (EXP. 1)

	Overall analysis of variance		Polynomial regression	
Source	df	Mean Square	df	Mean Square
Total	26	18.034	26	18.034
Pig	8	24.804	8	24.804
Period	2	21.159	2	21.159
Treatment	2	46.370	-	-
Linear	-	-	1	51.870
Quadratic	-	-	1	38.625
Error	14	9.670	14	9.670

TABLE 20. ANALYSIS OF VARIANCE FOR ILEAL THREONINE DIGESTIBILITY (EXP. 1)

	Overall analysis of variance		Polynomial regression	
Source	df	Mean Square	df	Mean Square
Total	26	27.881	26	27.881
Pig	8	42.022	8	42.022
Period	2	16.707	2	16.707
Treatment	2	58.889	-	-
Linear	-	-	1	16.312
Quadratic	-	-	1	29.556
Error	14	16.968	14	16.968

TABLE 21. ANALYSIS OF VARIANCE FOR ILEAL SERINE DIGESTIBILITY (EXP. 1)

	Overall analysis of variance		Polynomial regression	
Source	df	Mean Square	df	Mean Square
Total	26	33.744	26	33.744
Pig	8	49.027	8	49.027
Period	2	21.658	2	21.658
Treatment	2	126.800	-	-
Linear	-	-	1	199.125
Quadratic	-	-	1	225.625
Error	14	13.443	14	13.443

TABLE 22. ANALYSIS OF VARIANCE FOR ILEAL GLUTAMIC ACID DIGESTIBILITY (EXP. 1)

	Overall analysis of variance		Polynomial regression	
Source	df	Mean Square	df	Mean Square
Total	26	26.390	26	26.390
Pig	8	31.860	8	31.860
Period	2	11.383	2	11.383
Treatment	2	150.706	-	-
Linear	-	-	1	280.879
Quadratic	-	-	1	297.041
Error	14	7.648	14	7.648

TABLE 23. ANALYSIS OF VARIANCE FOR ILEAL GLYCINE DIGESTIBILITY (EXP. 1)

	Overall analysis of variance		Polynomial regression	
Source	df	Mean Square	df	Mean Square
Total	26	38.767	26	38.767
Pig	8	20.097	8	20.097
Period	2	19.463	2	19.463
Treatment	2	285.167	-	-
Linear	-	-	1	549.919
Quadratic	-	-	1	569.076
Error	14	16.992	14	16.992

TABLE 24. ANALYSIS OF VARIANCE FOR ILEAL ALANINE DIGESTIBILITY (EXP. 1)

	Overall analysis of variance		Polynomial regression	
Source	df	Mean Square	df	Mean Square
Total	26	27.838	26	27.838
Pig	8	25.781	8	25.781
Period	2	16.713	2	16.713
Treatment	2	112.740	-	-
Linear	-	-	1	78.847
Quadratic	-	-	1	49.824
Error	14	18.474	14	18.474

TABLE 25. ANALYSIS OF VARIANCE FOR ILEAL VALINE DIGESTIBILITY (EXP. 1)

	Overall analysis of variance		Polynomial regression	
Source	df	Mean Square	df	Mean Square
Total	26	37.803	26	37.803
Pig	8	24.191	8	24.191
Period	2	38.400	2	38.400
Treatment	2	170.115	-	-
Linear	-	-	1	75.376
Quadratic	-	-	1	39.287
Error	14	26.595	14	26.595

TABLE 26. ANALYSIS OF VARIANCE FOR ILEAL ISOLEUCINE DIGESTIBILITY (EXP. 1)

	Overall analysis of variance		Polynomial regression	
Source	df	Mean Square	df	Mean Square
Total	26	67.518	26	67.518
Pig	8	51.303	8	51.303
Period	2	.468	2	.468
Treatment	2	222.639	-	-
Linear	-	-	1	242.608
Quadratic	-	-	1	179.088
Error	14	64.203	14	64.203

TABLE 27. ANALYSIS OF VARIANCE FOR ILEAL LEUCINE DIGESTIBILITY (EXP. 1)

	Overall analysis of variance		Polynomial regression	
Source	df	Mean Square	df	Mean Square
Total	26	41.442	26	41.442
Pig	8	32.658	8	32.658
Period	2	10.912	2	10.912
Treatment	2	186.231	-	-
Linear	-	-	1	135.090
Quadratic	-	-	1	86.539
Error	14	30.138	14	30.138

TABLE 28. ANALYSIS OF VARIANCE FOR ILEAL TYROSINE DIGESTIBILITY (EXP. 1)

	Overall analysis of variance		Polynomial regression	
Source	df	Mean Square	df	Mean Square
Total	26	376.006	26	376.006
Pig	8	190.022	8	190.022
Period	2	59.223	2	59.223
Treatment	2	2566.888	-	-
Linear	-	-	1	2280.633
Quadratic	-	-	1	1570.970
Error	14	214.554	14	214.554

TABLE 29. ANALYSIS OF VARIANCE FOR ILEAL PHENYLALANINE DIGESTIBILITY (EXP. 1)

	Overall analysis of variance		Polynomial regression	
Source	df	Mean Square	df	Mean Square
Total	26	34.063	26	34.063
Pig	8	18.192	8	18.192
Period	2	4.031	2	4.031
Treatment	2	157.181	-	-
Linear	-	-	1	120.007
Quadratic	-	-	1	78.337
Error	14	29.833	14	29.833

TABLE 30. ANALYSIS OF VARIANCE FOR ILEAL LYSINE DIGESTIBILITY (EXP. 1)

	Overall analysis of variance		Polynomial regression	
Source	df	Mean Square	df	Mean Square
Total	26	100.432	26	100.432
Pig	8	87.791	8	87.791
Period	2	104.429	2	104.429
Treatment	2	122.217	-	-
Linear	-	-	1	3.484
Quadratic	-	-	1	16.523
Error	14	103.973	14	103.973

TABLE 31. ANALYSIS OF VARIANCE FOR ILEAL HISTIDINE DIGESTIBILITY (EXP. 1)

	Overall analysis of variance		Polynomial regression	
Source	df	Mean Square	df	Mean Square
Total	26	119.443	26	119.443
Pig	8	117.953	8	117.953
Period	2	76.101	2	76.101
Treatment	2	207.902	-	-
Linear	-	-	1	1.553
Quadratic	-	-	1	17.147
Error	14	113.849	14	113.849

TABLE 32. ANALYSIS OF VARIANCE FOR ILEAL ARGININE DIGESTIBILITY (EXP. 1)

	Overall analysis of variance		Polynomial regression	
Source	df	Mean Square	df	Mean Square
Total	26	7.744	26	7.744
Pig	8	3.937	8	3.937
Period	2	8.927	2	8.927
Treatment	2	1.285	-	-
Linear	-	-	1	.765
Quadratic	-	-	1	.454
Error	14	10.675	14	10.675

TABLE 33. ANALYSIS OF VARIANCE FOR FECAL ASPARTIC ACID DIGESTIBILITY (EXP. 1)

	Overall analysis of variance		Polynomial regression	
Source	df	Mean Square	df	Mean Square
Total	25	32.142	25	32.142
Pig	8	32.799	8	32.799
Period	2	9.480	2	9.480
Treatment	2	153.901	-	-
Linear	-	-	1	41.035
Quadratic	-	-	1	15.268
Error	13	16.491	13	16.491

TABLE 34. ANALYSIS OF VARIANCE FOR FECAL THREONINE DIGESTIBILITY (EXP. 1)

	Overall analysis of variance		Polynomial regression	
Source	df	Mean Square	df	Mean Square
Total	25	48.581	25	48.581
Pig	8	58.482	8	58.482
Period	2	40.538	2	40.538
Treatment	2	161.111	-	-
Linear	-	-	1	167.885
Quadratic	-	-	1	214.897
Error	13	26.413	13	26.413

TABLE 35. ANALYSIS OF VARIANCE FOR FECAL SERINE DIGESTIBILITY (EXP. 1)

	Overall analysis of variance		Polynomial regression	
Source	df	Mean Square	df	Mean Square
Total	25	28.736	25	28.736
Pig	8	25.306	8	25.306
Period	2	5.342	2	5.342
Treatment	2	189.926	-	-
Linear	-	-	1	269.173
Quadratic	-	-	1	316.404
Error	13	9.648	13	9.648

TABLE 36. ANALYSIS OF VARIANCE FOR FECAL GLUTAMIC ACID DIGESTIBILITY (EXP. 1)

	Overall analysis of variance		Polynomial regression	
Source	df	Mean Square	df	Mean Square
Total	25	26.184	25	26.184
Pig	8	84.731	8	84.731
Period	2	4.055	2	4.055
Treatment	2	189.711	-	-
Linear	-	-	1	279.849
Quadratic	-	-	1	324.931
Error	13	7.508	13	7.508

TABLE 37. ANALYSIS OF VARIANCE FOR FECAL GLYCINE DIGESTIBILITY (EXP. 1)

	Overall analysis of variance		Polynomial regression	
Source	df	Mean Square	df	Mean Square
Total	25	22.075	25	22.075
Pig	8	4.911	8	4.911
Period	2	2.754	2	2.754
Treatment	2	189.629	-	-
Linear	-	-	1	338.177
Quadratic	-	-	1	366.259
Error	13	9.832	13	9.832

TABLE 38. ANALYSIS OF VARIANCE FOR FECAL ALANINE DIGESTIBILITY (EXP. 1)

	Overall analysis of variance		Polynomial regression	
Source	df	Mean Square	df	Mean Square
Total	25	63.039	25	63.039
Pig	8	53.988	8	53.988
Period	2	40.122	2	40.122
Treatment	2	237.694	-	-
Linear	-	-	1	31.469
Quadratic	-	-	1	5.839
Error	13	45.264	13	45.264

TABLE 39. ANALYSIS OF VARIANCE FOR FECAL VALINE DIGESTIBILITY (EXP. 1)

	Overall analysis of variance		Polynomial regression	
Source	df	Mean Square	df	Mean Square
Total	25	48.369	25	48.369
Pig	8	48.969	8	48.969
Period	2	6.187	2	6.187
Treatment	2	185.843	-	-
Linear	-	-	1	37.075
Quadratic	-	-	1	10.909
Error	13	30.485	13	30.485

TABLE 40. ANALYSIS OF VARIANCE FOR FECAL ISOLEUCINE DIGESTIBILITY (EXP. 1)

	Overall analysis of variance		Polynomial regression	
Source	df	Mean Square	df	Mean Square
Total	25	106.793	25	106.793
Pig	8	93.916	8	93.916
Period	2	66.172	2	66.172
Treatment	2	269.233	-	-
Linear	-	-	1	57.117
Quadratic	-	-	1	17.751
Error	13	95.976	13	95.976

TABLE 41. ANALYSIS OF VARIANCE FOR FECAL LEUCINE DIGESTIBILITY (EXP. 1)

	Overall analysis of variance		Polynomial regression	
Source	df	Mean Square	df	Mean Square
Total	25	31.513	25	31.513
Pig	8	49.906	8	49.906
Period	2	9.739	2	9.739
Treatment	2	71.249	-	-
Linear	-	-	1	26.605
Quadratic	-	-	1	12.256
Error	13	17.430	13	17.430

TABLE 42. ANALYSIS OF VARIANCE FOR FECAL TYROSINE DIGESTIBILITY (EXP. 1)

	Overall analysis of variance		Polynomial regression	
Source	df	Mean Square	df	Mean Square
Total	25	683.789	25	683.789
Pig	8	564.618	8	564.618
Period	2	1021.304	2	1021.304
Treatment	2	3220.229	-	-
Linear	-	-	1	1905.875
Quadratic	-	-	1	1099.872
Error	13	314.979	13	314.979

TABLE 43. ANALYSIS OF VARIANCE FOR FECAL PHENYLALANINE DIGESTIBILITY (EXP. 1)

	Overall analysis of variance		Polynomial regression	
Source	df	Mean Square	df	Mean Square
Total	25	41.425	25	41.425
Pig	8	33.977	8	33.977
Period	2	57.245	2	57.245
Treatment	2	127.775	-	-
Linear	-	-	1	44.356
Quadratic	-	-	1	19.593
Error	13	30.289	13	30.289

TABLE 44. ANALYSIS OF VARIANCE FOR FECAL LYSINE DIGESTIBILITY (EXP. 1)

	Overall analysis of variance		Polynomial regression	
Source	df	Mean Square	df	Mean Square
Total	25	96.547	25	96.547
Pig	8	116.673	8	116.673
Period	2	.264	2	.264
Treatment	2	523.795	-	-
Linear	-	-	1	17.346
Quadratic	-	-	1	79.007
Error	13	33.244	13	33.244

TABLE 45. ANALYSIS OF VARIANCE FOR FECAL HISTIDINE DIGESTIBILITY (EXP. 1)

	Overall analysis of variance		Polynomial regression	
Source	df	Mean Square	df	Mean Square
Total	25	56.377	25	56.377
Pig	8	87.831	8	87.831
Period	2	8.312	2	8.312
Treatment	2	160.424	-	-
Linear	-	-	1	160.885
Quadratic	-	-	1	113.714
Error	13	28.408	13	28.408

TABLE 46. ANALYSIS OF VARIANCE FOR FECAL ARGININE DIGESTIBILITY (EXP. 1)

	Overall analysis of variance		Polynomial regression	
Source	df	Mean Square	df	Mean Square
Total	25	7.914	25	7.914
Pig	8	8.663	8	8.663
Period	2	11.587	2	11.587
Treatment	2	21.926	-	-
Linear	-	-	1	8.895
Quadratic	-	-	1	14.654
Error	13	4.733	13	4.733

TABLE 47. ANALYSIS OF VARIANCE FOR FECAL NITROGEN DIGESTIBILITY (EXP. 2)

	Overall analysis of variance		Polynomial regression	
Source	df	Mean Square	df	Mean Square
Total	26	26.590	26	26.590
Pig	8	28.042	8	28.042
Period	2	6.018	2	6.018
Treatment	2	11.079	-	-
Linear	-	-	1	7.741
Quadratic	-	-	1	4.890
Error	14	30.916	14	30.916

TABLE 48. ANALYSIS OF VARIANCE FOR FECAL DRY MATTER DIGESTIBILITY (EXP. 2)

	Overall analysis of variance		Polynomial regression	
Source	df	Mean Square	df	Mean Square
Total	26	17.745	26	17.745
Pig	8	5.824	8	5.824
Period	2	2.129	2	2.129
Treatment	2	2.278	-	-
Linear	-	-	1	.484
Quadratic	-	-	1	.163
Error	14	29.005	14	29.005

TABLE 49. ANALYSIS OF VARIANCE FOR FECAL NEUTRAL DETERGENT FIBER DIGESTIBILITY (EXP. 2)

	Overall analysis of variance		Polynomial regression	
Source	df	Mean Square	df	Mean Square
Total	26	197.134	26	197.134
Pig	8	73.997	8	73.997
Period	2	9.087	2	9.087
Treatment	2	248.492	-	-
Linear	-	-	1	23.494
Quadratic	-	-	1	2.852
Error	14	287.026	14	287.026

TABLE 50. ANALYSIS OF VARIANCE FOR FECAL ACID DETERGENT FIBER DIGESTIBILITY (EXP. 2)

	Overall analysis of variance		Polynomial regression	
Source	df	Mean Square	df	Mean Square
Total	26	786.299	26	786.299
Pig	8	238.662	8	238.662
Period	2	35.204	2	35.204
Treatment	2	3401.771	-	-
Linear	-	-	1	852.471
Quadratic	-	-	1	319.594
Error	14	832.824	14	832.824

TABLE 51. ANALYSIS OF VARIANCE FOR FECAL CRUDE FIBER DIGESTIBILITY (EXP. 2)

	Overall analysis of variance		Polynomial regression	
Source	df	Mean Square	df	Mean Square
Total	26	1413.451	26	1413.451
Pig	8	356.619	8	356.619
Period	2	138.196	2	138.196
Treatment	2	7426.254	-	-
Linear	-	-	1	1895.432
Quadratic	-	-	1	719.780
Error	14	1340.564	14	1340.564

TABLE 52. ANALYSIS OF VARIANCE FOR FECAL CELLULOSE DIGESTIBILITY (EXP. 2)

	Overall analysis of variance		Polynomial regression	
Source	df	Mean Square	df	Mean Square
Total	26	504.512	26	504.512
Pig	8	148.341	8	148.341
Period	2	15.327	2	15.327
Treatment	2	1667.464	-	-
Linear	-	-	1	410.084
Quadratic	-	-	1	151.705
Error	14	611.786	14	611.786

TABLE 53. ANALYSIS OF VARIANCE FOR FECAL LIGNIN DIGESTIBILITY (EXP. 2)

	Overall analysis of variance		Polynomial regression	
Source	df	Mean Square	df	Mean Square
Total	26	2037.309	26	2037.309
Pig	8	584.395	8	584.395
Period	2	182.213	2	182.213
Treatment	2	12524.006	-	-
Linear	-	-	1	6577.712
Quadratic	-	-	1	3703.479
Error	14	1634.459	14	1634.459

TABLE 54. ANALYSIS OF VARIANCE FOR FECAL HEMICELLULOSE DIGESTIBILITY (EXP. 2)

	Overall analysis of variance		Polynomial regression	
Source	df	Mean Square	df	Mean Square
Total	26	68.260	26	68.260
Pig	8	65.646	8	65.646
Period	2	39.605	2	39.605
Treatment	2	14.230	-	-
Linear	-	-	1	1.597
Quadratic	-	-	1	.260
Error	14	81.565	14	81.565

TABLE 55. ANALYSIS OF VARIANCE FOR FECAL ASH DIGESTIBILITY (EXP. 2)

	Overall analysis of variance		Polynomial regression	
Source	df	Mean Square	df	Mean Square
Total	26	51.858	26	51.858
Pig	8	20.170	8	20.170
Period	2	99.485	2	99.485
Treatment	2	28.337	-	-
Linear	-	-	1	.422
Quadratic	-	-	1	2.94
Error	14	66.521	14	66.521

TABLE 56. ANALYSIS OF VARIANCE FOR ILEAL NITROGEN DIGESTIBILITY (EXP. 2)

	Overall analysis of variance		Polynomial regression	
Source	df	Mean Square	df	Mean Square
Total	26	48.582	26	48.582
Pig	8	65.426	8	65.426
Period	2	27.022	2	27.022
Treatment	2	36.963	-	-
Linear	-	-	1	.107
Quadratic	-	-	1	2.407
Error	14	43.696	14	43.696

TABLE 57. ANALYSIS OF VARIANCE FOR ILEAL DRY MATTER DIGESTIBILITY (EXP. 2)

	Overall analysis of variance		Polynomial regression	
Source	df	Mean Square	df	Mean Square
Total	26	27.443	26	27.443
Pig	8	12.295	8	12.295
Period	2	34.491	2	34.491
Treatment	2	73.749	-	-
Linear	-	-	1	.011
Quadratic	-	-	1	2.658
Error	14	28.477	14	28.477

TABLE 58. ANALYSIS OF VARIANCE FOR ILEAL NEUTRAL DETERGENT FIBER DIGESTIBILITY (EXP. 2)

	Overall analysis of variance		Polynomial regression	
Source	df	Mean Square	df	Mean Square
Total	26	149.416	26	149.416
Pig	8	51.686	8	51.686
Period	2	4.080	2	4.080
Treatment	2	343.522	-	-
Linear	-	-	1	.071
Quadratic	-	-	1	12.098
Error	14	198.332	14	198.332

TABLE 59. ANALYSIS OF VARIANCE FOR ILEAL ACID DETERGENT FIBER DIGESTIBILITY (EXP. 2)

	Overall analysis of variance		Polynomial regression	
Source	df	Mean Square	df	Mean Square
Total	26	774.694	26	774.694
Pig	8	90.052	8	90.052
Period	2	200.264	2	200.264
Treatment	2	5182.985	-	-
Linear	-	-	1	506.756
Quadratic	-	-	1	65.538
Error	14	618.224	14	618.224

TABLE 60. ANALYSIS OF VARIANCE FOR ILEAL CRUDE FIBER DIGESTIBILITY (EXP. 2)

	Overall analysis of variance		Polynomial regression	
Source	df	Mean Square	df	Mean Square
Total	26	1479.932	26	1479.932
Pig	8	264.798	8	264.798
Period	2	461.528	2	461.528
Treatment	2	10657.932	-	-
Linear	-	-	1	1659.494
Quadratic	-	-	1	366.185
Error	14	1008.638	14	1008.638

TABLE 61. ANALYSIS OF VARIANCE FOR ILEAL CELLULOSE DIGESTIBILITY (EXP. 2)

	Overall analysis of variance		Polynomial regression	
Source	df	Mean Square	df	Mean Square
Total	26	634.845	26	634.845
Pig	8	115.290	8	115.290
Period	2	191.587	2	191.587
Treatment	2	3711.426	-	-
Linear	-	-	1	122.402
Quadratic	-	-	1	1.578
Error	14	555.544	14	555.544

TABLE 62. ANALYSIS OF VARIANCE FOR ILEAL LIGNIN DIGESTIBILITY (EXP. 2)

	Overall analysis of variance		Polynomial regression	
Source	df	Mean Square	df	Mean Square
Total	26	1383.233	26	1383.233
Pig	8	155.634	8	155.634
Period	2	477.340	2	477.340
Treatment	2	9953.266	-	-
Linear	-	-	1	5072.451
Quadratic	-	-	1	2818.689
Error	14	989.840	14	989.840

TABLE 63. ANALYSIS OF VARIANCE FOR ILEAL HEMICELLULOSE DIGESTIBILITY (EXP. 2)

	Overall analysis of variance		Polynomial regression	
Source	df	Mean Square	df	Mean Square
Total	26	46.068	26	46.068
Pig	8	46.416	8	46.416
Period	2	35.907	2	35.907
Treatment	2	71.849	-	-
Linear	-	-	1	.263
Quadratic	-	-	1	4.920
Error	14	43.637	14	43.637

TABLE 64. ANALYSIS OF VARIANCE FOR ILEAL ASH DIGESTIBILITY (EXP. 2)

	Overall analysis of variance		Polynomial regression	
Source	df	Mean Square	df	Mean Square
Total	26	54.561	26	54.561
Pig	8	22.459	8	22.459
Period	2	300.091	2	300.091
Treatment	2	61.840	-	-
Linear	-	-	1	103.050
Quadratic	-	-	1	114.407
Error	14	36.790	14	36.790

TABLE 65. ANALYSIS OF VARIANCE FOR ILEAL ASPARTIC ACID DIGESTIBILITY (EXP. 2)

	Overall analysis of variance		Polynomial regression	
Source	df	Mean Square	df	Mean Square
Total	26	52.813	26	52.813
Pig	8	51.591	8	51.591
Period	2	133.922	2	133.922
Treatment	2	210.341	-	-
Linear	-	-	1	180.274
Quadratic	-	-	1	240.371
Error	14	19.421	14	19.421

TABLE 66. ANALYSIS OF VARIANCE FOR ILEAL THREONINE DIGESTIBILITY (EXP. 2)

	Overall analysis of variance		Polynomial regression	
Source	df	Mean Square	df	Mean Square
Total	26	41.860	26	41.860
Pig	8	38.935	8	38.935
Period	2	68.181	2	68.181
Treatment	2	114.259	-	-
Linear	-	-	1	127.589
Quadratic	-	-	1	159.135
Error	14	29.430	14	29.430

TABLE 67. ANALYSIS OF VARIANCE FOR ILEAL SERINE DIGESTIBILITY (EXP. 2)

	Overall analysis of variance		Polynomial regression	
Source	df	Mean Square	df	Mean Square
Total	26	31.539	26	31.539
Pig	8	43.988	8	43.988
Period	2	35.831	2	35.831
Treatment	2	35.621	-	-
Linear	-	-	1	44.059
Quadratic	-	-	1	53.501
Error	14	23.229	14	23.229

TABLE 68. ANALYSIS OF VARIANCE FOR ILEAL GLUTAMIC ACID DIGESTIBILITY (EXP. 2)

	Overall analysis of variance		Polynomial regression	
Source	df	Mean Square	df	Mean Square
Total	26	32.682	26	32.682
Pig	8	43.767	8	43.767
Period	2	59.555	2	59.555
Treatment	2	77.90	-	-
Linear	-	-	1	48.849
Quadratic	-	-	1	70.475
Error	14	16.049	14	16.049

TABLE 69. ANALYSIS OF VARIANCE FOR ILEAL GLYCINE DIGESTIBILITY (EXP. 2)

	Overall analysis of variance		Polynomial regression	
Source	df	Mean Square	df	Mean Square
Total	26	50.374	26	50.374
Pig	8	31.252	8	31.252
Period	2	60.921	2	60.921
Treatment	2	104.462	-	-
Linear	-	-	1	67.956
Quadratic	-	-	1	97.123
Error	14	52.069	14	52.069

TABLE 70. ANALYSIS OF VARIANCE FOR ILEAL ALANINE DIGESTIBILITY (EXP. 2)

	Overall analysis of variance		Polynomial regression	
Source	df	Mean Square	df	Mean Square
Total	26	69.364	26	69.364
Pig	8	62.004	8	62.004
Period	2	92.222	2	92.222
Treatment	2		-	-
Linear	-	-	1	47.917
Quadratic	-	-	1	26.853
Error	14	71.674	14	71.674

TABLE 71. ANALYSIS OF VARIANCE FOR ILEAL VALINE DIGESTIBILITY (EXP. 2)

	Overall analysis of variance		Polynomial regression	
Source	df	Mean Square	df	Mean Square
Total	26	92.323	26	92.323
Pig	8	58.874	8	58.874
Period	2	264.356	2	264.356
Treatment	2	407.756	-	-
Linear	-	-	1	21.311
Quadratic	-	-	1	73.874
Error	14	41.799	14	41.799

TABLE 72. ANALYSIS OF VARIANCE FOR ILEAL ISOLEUCINE DIGESTIBILITY (EXP. 2)

	Overall analysis of variance		Polynomial regression	
Source	df	Mean Square	df	Mean Square
Total	26	57.990	26	57.990
Pig	8	26.673	8	26.673
Period	2	247.98	2	247.980
Treatment	2	164.668	-	-
Linear	-	-	1	1.811
Quadratic	-	-	1	1.571
Error	14	33.505	14	33.505

TABLE 73. ANALYSIS OF VARIANCE FOR ILEAL LEUCINE DIGESTIBILITY (EXP. 2)

	Overall analysis of variance		Polynomial regression	
Source	df	Mean Square	df	Mean Square
Total	26	32.977	26	32.977
Pig	8	26.949	8	26.949
Period	2	101.791	2	101.791
Treatment	2	87.536	-	-
Linear	-	-	1	.164
Quadratic	-	-	1	2.216
Error	14	18.798	14	18.798

TABLE 74. ANALYSIS OF VARIANCE FOR ILEAL TYROSINE DIGESTIBILITY (EXP. 2)

	Overall analysis of variance		Polynomial regression	
Source	df	Mean Square	df	Mean Square
Total	26	105.686	26	105.686
Pig	8	87.524	8	87.524
Period	2	120.648	2	120.648
Treatment	2	38.092	-	-
Linear	-	-	1	21.476
Quadratic	-	-	1	31.847
Error	14	123.584	14	123.584

TABLE 75. ANALYSIS OF VARIANCE FOR ILEAL PHENYLALANINE DIGESTIBILITY (EXP. 2)

	Overall analysis of variance		Polynomial regression	
Source	df	Mean Square	df	Mean Square
Total	26	38.858	26	38.858
Pig	8	35.787	8	35.787
Period	2	86.636	2	86.636
Treatment	2	111.410	-	-
Linear	-	-	1	4.025
Quadratic	-	-	1	16.778
Error	14	23.461	14	23.461

TABLE 76. ANALYSIS OF VARIANCE FOR ILEAL LYSINE DIGESTIBILITY (EXP. 2)

	Overall analysis of variance		Polynomial regression	
Source	df	Mean Square	df	Mean Square
Total	26	93.525	26	93.525
Pig	8	151.327	8	151.327
Period	2	77.659	2	77.659
Treatment	2	334.821	-	-
Linear	-	-	1	393.896
Quadratic	-	-	1	484.681
Error	14	28.291	14	28.291

TABLE 77. ANALYSIS OF VARIANCE FOR ILEAL HISTIDINE DIGESTIBILITY (EXP. 2)

	Overall analysis of variance		Polynomial regression	
Source	df	Mean Square	df	Mean Square
Total	26	50.187	26	50.187
Pig	8	54.671	8	54.671
Period	2	98.267	2	98.267
Treatment	2	204.091	-	-
Linear	-	-	1	337.418
Quadratic	-	-	1	375.672
Error	14	18.770	14	18.770

TABLE 78. ANALYSIS OF VARIANCE FOR ILEAL ARGININE DIGESTIBILITY (EXP. 2)

	Overall analysis of variance		Polynomial regression	
Source	df	Mean Square	df	Mean Square
Total	26	36.503	26	36.503
Pig	8	38.535	8	38.535
Period	2	75.005	2	75.005
Treatment	2	138.018	-	-
Linear	-	-	1	213.920
Quadratic	-	-	1	243.419
Error	14	15.339	14	15.339

TABLE 79. ANALYSIS OF VARIANCE FOR FECAL ASPARTIC ACID DIGESTIBILITY (EXP. 2)

	Overall analysis of variance		Polynomial regression	
Source	df	Mean Square	df	Mean Square
Total	26	25.918	26	25.918
Pig	8	25.359	8	25.359
Period	2	19.208	2	19.208
Treatment	2	60.646	-	-
Linear	-	-	1	27.130
Quadratic	-	-	1	42.791
Error	14	22.234	14	22.234

TABLE 80. ANALYSIS OF VARIANCE FOR FECAL THREONINE DIGESTIBILITY (EXP. 2)

	Overall analysis of variance		Polynomial regression	
Source	df	Mean Square	df	Mean Square
Total	26	28.580	26	28.580
Pig	8	19.273	8	19.273
Period	2	48.167	2	48.167
Treatment	2	55.070	-	-
Linear	-	-	1	64.357
Quadratic	-	-	1	79.328
Error	14	27.317	14	27.317

TABLE 81. ANALYSIS OF VARIANCE FOR FECAL SERINE DIGESTIBILITY (EXP. 2)

	Overall analysis of variance		Polynomial regression	
Source	df	Mean Square	df	Mean Square
Total	26	14.973	26	14.973
Pig	8	14.423	8	14.423
Period	2	20.356	2	20.356
Treatment	2	15.572	-	-
Linear	-	-	1	6.850
Quadratic	-	-	1	10.854
Error	14	14.433	14	14.433

TABLE 82. ANALYSIS OF VARIANCE FOR FECAL GLUTAMIC ACID DIGESTIBILITY (EXP. 2)

	Overall analysis of variance		Polynomial regression	
Source	df	Mean Square	df	Mean Square
Total	26	8.082	26	8.082
Pig	8	10.039	8	10.039
Period	2	13.468	2	13.468
Treatment	2	8.140	-	-
Linear	-	-	1	2.302
Quadratic	-	-	1	4.144
Error	14	6.186	14	6.186

TABLE 83. ANALYSIS OF VARIANCE FOR FECAL GLYCINE DIGESTIBILITY (EXP. 2)

	Overall analysis of variance		Polynomial regression	
Source	df	Mean Square	df	Mean Square
Total	26	17.647	26	17.647
Pig	8	14.289	8	14.289
Period	2	6.586	2	6.586
Treatment	2	10.251	-	-
Linear	-	-	1	.605
Quadratic	-	-	1	1.979
Error	14	22.203	14	22.203

TABLE 84. ANALYSIS OF VARIANCE FOR FECAL ALANINE DIGESTIBILITY (EXP. 2)

	Overall analysis of variance		Polynomial regression	
Source	df	Mean Square	df	Mean Square
Total	26	37.664	26	37.664
Pig	8	27.248	8	27.248
Period	2	57.535	2	57.535
Treatment	2	72.462	-	-
Linear	-	-	1	.227
Quadratic	-	-	1	1.554
Error	14	35.763	14	35.763

TABLE 85. ANALYSIS OF VARIANCE FOR FECAL VALINE DIGESTIBILITY (EXP. 2)

	Overall analysis of variance		Polynomial regression	
Source	df	Mean Square	df	Mean Square
Total	26	68.336	26	68.336
Pig	8	16.976	8	16.976
Period	2	97.854	2	97.854
Treatment	2	348.644	-	-
Linear	-	-	1	8.165
Quadratic	-	-	1	43.273
Error	14	53.424	14	53.424

TABLE 86. ANALYSIS OF VARIANCE FOR FECAL ISOLEUCINE DIGESTIBILITY (EXP. 2)

	Overall analysis of variance		Polynomial regression	
Source	df	Mean Square	df	Mean Square
Total	26	40.871	26	40.871
Pig	8	22.904	8	20.904
Period	2	117.666	2	117.666
Treatment	2	70.087	-	-
Linear	-	-	1	43.108
Quadratic	-	-	1	25.917
Error	14	35.994	14	35.994

TABLE 87. ANALYSIS OF VARIANCE FOR FECAL LEUCINE DIGESTIBILITY (EXP. 2)

	Overall analysis of variance		Polynomial regression	
Source	df	Mean Square	df	Mean Square
Total	26	20.731	26	20.731
Pig	8	16.689	8	16.689
Period	2	37.811	2	37.811
Treatment	2	22.983	-	-
Linear	-	-	1	6.661
Quadratic	-	-	1	2.752
Error	14	20.278	14	20.278

TABLE 88. ANALYSIS OF VARIANCE FOR FECAL TYROSINE DIGESTIBILITY (EXP. 2)

	Overall analysis of variance		Polynomial regression	
Source	df	Mean Square	df	Mean Square
Total	26	167.993	26	167.993
Pig	8	157.692	8	157.692
Period	2	351.402	2	351.402
Treatment	2	239.818	-	-
Linear	-	-	1	177.033
Quadratic	-	-	1	114.145
Error	14	137.418	14	137.418

TABLE 89. ANALYSIS OF VARIANCE FOR FECAL PHENYLALANINE DIGESTIBILITY (EXP. 2)

	Overall analysis of variance		Polynomial regression	
Source	df	Mean Square	df	Mean Square
Total	26	20.681	26	20.681
Pig	8	19.108	8	19.108
Period	2	47.842	2	47.842
Treatment	2	9.389	-	-
Linear	-	-	1	.006
Quadratic	-	-	1	.293
Error	14	19.313	14	19.313

TABLE 90. ANALYSIS OF VARIANCE FOR FECAL LYSINE DIGESTIBILITY (EXP. 2)

	Overall analysis of variance		Polynomial regression	
Source	df	Mean Square	df	Mean Square
Total	26	26.092	26	26.092
Pig	8	16.474	8	16.474
Period	2	22.531	2	22.531
Treatment	2	109.897	-	-
Linear	-	-	1	.491
Quadratic	-	-	1	7.889
Error	14	20.124	14	20.124

TABLE 91. ANALYSIS OF VARIANCE FOR FECAL HISTIDINE DIGESTIBILITY (EXP. 2)

	Overall analysis of variance		Polynomial regression	
Source	df	Mean Square	df	Mean Square
Total	26	11.013	26	11.013
Pig	8	9.015	8	9.015
Period	2	16.323	2	16.323
Treatment	2	7.533	-	-
Linear	-	-	1	2.983
Quadratic	-	-	1	4.866
Error	14	11.894	14	11.894

TABLE 92. ANALYSIS OF VARIANCE FOR FECAL ARGININE DIGESTIBILITY (EXP. 2)

	Overall analysis of variance		Polynomial regression	
Source	df	Mean Square	df	Mean Square
Total	26	6.639	26	6.639
Pig	8	5.764	8	5.764
Period	2	13.334	2	13.334
Treatment	2	12.809	-	-
Linear	-	-	1	1.498
Quadratic	-	-	1	3.661
Error	14	5.303	14	5.303

TABLE 93. ANALYSIS OF VARIANCE FOR FECAL NITROGEN DIGESTIBILITY (EXP. 3)

	Overall analysis of variance		Factorial analysis of variance	
Source	df	Mean Square	df	Mean Square
Total	47	66.504	47	66.504
Pig	11	84.665	11	84.665
Period	3	264.604	3	264.604
Treatment	3	348.751	-	-
Fiber	-	-	1	736.490
Protein	-	-	1	295.418
Error	30	11.810	31	11.892

TABLE 94. ANALYSIS OF VARIANCE FOR FECAL DRY MATTER DIGESTIBILITY (EXP. 3)

	Overall analysis of variance		Factorial analysis of variance	
Source	df	Mean Square	df	Mean Square
Total	47	58.825	47	58.825
Pig	11	55.358	11	55.358
Period	3	119.861	3	119.861
Treatment	3	503.142	-	-
Fiber	-	-	1	1498.121
Protein	-	-	1	5.070
Error	30	9.561	31	9.454

TABLE 95. ANALYSIS OF VARIANCE FOR FECAL NEUTRAL DETERGENT FIBER DIGESTIBILITY (EXP. 3)

	Overall analysis of variance		Factorial analysis of variance	
Source	df	Mean Square	df	Mean Square
Total	47	273.412	47	273.412
Pig	11	506.394	11	506.394
Period	3	716.429	3	716.429
Treatment	3	301.230	-	-
Fiber	-	-	1	496.332
Protein	-	-	1	363.715
Error	30	140.902	31	137.765

TABLE 96. ANALYSIS OF VARIANCE FOR FECAL ACID DETERGENT FIBER DIGESTIBILITY (EXP. 3)

	Overall analysis of variance		Factorial analysis of variance	
Source	df	Mean Square	df	Mean Square
Total	47	423.395	47	423.395
Pig	11	698.199	11	698.199
Period	3	1440.368	3	1440.368
Treatment	3	1017.503	-	-
Fiber	-	-	1	2501.008
Protein	-	-	1	490.752
Error	30	161.526	31	158.275

TABLE 97. ANALYSIS OF VARIANCE FOR FECAL CELLULOSE DIGESTIBILITY (EXP. 3)

	Overall analysis of variance		Factorial analysis of variance	
Source	df	Mean Square	df	Mean Square
Total	47	463.661	47	463.661
Pig	11	590.491	11	590.491
Period	3	1395.267	3	1395.267
Treatment	3	2433.488	-	-
Fiber	-	-	1	6894.491
Protein	-	-	1	399.688
Error	30	127.013	31	123.118

TABLE 98. ANALYSIS OF VARIANCE FOR FECAL LIGNIN DIGESTIBILITY (EXP. 3)

	Overall analysis of variance		Factorial analysis of variance	
Source	df	Mean Square	df	Mean Square
Total	47	387.499	47	387.499
Pig	11	729.903	11	729.903
Period	3	693.627	3	693.627
Treatment	3	334.885	-	-
Fiber	-	-	1	489.985
Protein	-	-	1	4.675
Error	30	236.600	31	245.420

TABLE 99. ANALYSIS OF VARIANCE FOR FECAL HEMICELLULOSE DIGESTIBILITY (EXP. 3)

	Overall analysis of variance		Factorial analysis of variance	
Source	df	Mean Square	df	Mean Square
Total	47	394.067	47	394.067
Pig	11	452.617	11	452.617
Period	3	113.733	3	113.733
Treatment	3	700.251	-	-
Fiber	-	-	1	821.377
Protein	-	-	1	349.920
Error	30	370.013	31	388.060

TABLE 100. ANALYSIS OF VARIANCE FOR FECAL ASH DIGESTIBILITY (EXP. 3)

	Overall analysis of variance		Factorial analysis of variance	
Source	df	Mean Square	df	Mean Square
Total	47	197.999	47	197.999
Pig	11	240.181	11	240.181
Period	3	596.885	3	596.885
Treatment	3	279.583	-	-
Fiber	-	-	1	834.334
Protein	-	-	1	2.930
Error	30	134.486	31	130.196

TABLE 101. ANALYSIS OF VARIANCE FOR ILEAL NITROGEN DIGESTIBILITY (EXP. 3)

	Overall analysis of variance		Factorial analysis of variance	
Source	df	Mean Square	df	Mean Square
Total	47	21.955	47	21.955
Pig	11	21.830	11	21.830
Period	3	22.658	3	22.658
Treatment	3	78.814	-	-
Fiber	-	-	1	3.876
Protein	-	-	1	228.028
Error	30	16.245	31	15.867

TABLE 102. ANALYSIS OF VARIANCE FOR ILEAL DRY MATTER DIGESTIBILITY (EXP.3)

	Overall analysis of variance		Factorial analysis of variance	
Source	df	Mean Square	df	Mean Square
Total	47	39.587	47	39.587
Pig	11	13.681	11	13.681
Period	3	6.427	3	6.427
Treatment	3	455.747	-	-
Fiber	-	-	1	1354.475
Protein	-	-	1	10.641
Error	30	10.786	31	10.507

TABLE 103. ANALYSIS OF VARIANCE FOR ILEAL NEUTRAL DETERGENT FIBER DIGESTIBILITY (EXP. 3)

	Overall analysis of variance		Factorial analysis of variance	
Source	df	Mean Square	df	Mean Square
Total	47	81.563	47	81.563
Pig	11	53.602	11	53.602
Period	3	166.227	3	166.227
Treatment	3	140.052	-	-
Fiber	-	-	1	418.665
Protein	-	-	1	.980
Error	30	77.501	31	75.017

TABLE 104. ANALYSIS OF VARIANCE FOR ILEAL ACID DETERGENT FIBER DIGESTIBILITY (EXP. 3)

	Overall analysis of variance		Factorial analysis of variance	
Source	df	Mean Square	df	Mean Square
Total	47	122.357	47	122.357
Pig	11	141.761	11	141.761
Period	3	410.876	3	410.876
Treatment	3	164.027	-	-
Fiber	-	-	1	363.165
Protein	-	-	1	38.467
Error	30	82.224	31	82.489

TABLE 105. ANALYSIS OF VARIANCE FOR ILEAL CELLULOSE DIGESTIBILITY (EXP. 3)

	Overall analysis of variance		Factorial analysis of variance	
Source	df	Mean Square	df	Mean Square
Total	47	268.133	47	268.133
Pig	11	304.328	11	304.328
Period	3	180.324	3	180.324
Treatment	3	452.085	-	-
Fiber	-	-	1	1303.751
Protein	-	-	1	2.689
Error	30	245.248	31	238.943

TABLE 106. ANALYSIS OF VARIANCE FOR ILEAL LIGNIN DIGESTIBILITY (EXP. 3)

	Overall analysis of variance		Factorial analysis of variance	
Source	df	Mean Square	df	Mean Square
Total	47	183.364	47	138.364
Pig	11	138.160	11	138.160
Period	3	732.132	3	732.132
Treatment	3	38.559	-	-
Fiber	-	-	1	40.059
Protein	-	-	1	24.013
Error	30	159.542	31	156.060

TABLE 107. ANALYSIS OF VARIANCE FOR ILEAL HEMICELLULOSE DIGESTIBILITY (EXP. 3)

	Overall analysis of variance		Factorial analysis of variance	
Source	df	Mean Square	df	Mean Square
Total	47	641.975	47	641.975
Pig	11	539.787	11	539.787
Period	3	636.329	3	636.329
Treatment	3	3539.222	-	-
Fiber	-	-	1	10190.841
Protein	-	-	1	19.076
Error	30	390.284	31	390.847

TABLE 108. ANALYSIS OF VARIANCE FOR ILEAL ASH DIGESTIBILITY (EXP. 3)

	Overall analysis of variance		Factorial analysis of variance	
Source	df	Mean Square	df	Mean Square
Total	47	68.583	47	68.583
Pig	11	48.652	11	48.652
Period	3	23.198	3	23.198
Treatment	3	471.186	-	-
Fiber	-	-	1	1129.759
Protein	-	-	1	246.115
Error	30	40.169	31	40.089

TABLE 109. ANALYSIS OF VARIANCE FOR ILEAL ASPARTIC ACID DIGESTIBILITY (EXP. 3)

	Overall analysis of variance		Factorial analysis of variance	
Source	df	Mean Square	df	Mean Square
Total	47	15.530	47	15.530
Pig	11	7.333	11	7.333
Period	3	25.210	3	25.100
Treatment	3	18.828	-	-
Fiber	-	-	1	50.287
Protein	-	-	1	.684
Fiber * Protein	-	-	1	5.515
Error	30	17.237	30	17.237

TABLE 110. ANALYSIS OF VARIANCE FOR ILEAL THREONINE DIGESTIBILITY (EXP. 3)

	Overall analysis of variance		Factorial analysis of variance	
Source	df	Mean Square	df	Mean Square
Total	47	20.632	47	20.632
Pig	11	17.998	11	17.998
Period	3	7.175	3	7.175
Treatment	3	41.395	-	-
Fiber	-	-	1	123.264
Protein	-	-	1	.062
Fiber * Protein	-	-	1	.859
Error	30	20.867	30	20.867

TABLE 111. ANALYSIS OF VARIANCE FOR ILEAL SERINE DIGESTIBILITY (EXP. 3)

	Overall analysis of variance		Factorial analysis of variance	
Source	df	Mean Square	df	Mean Square
Total	47	22.659	47	22.659
Pig	11	8.341	11	8.341
Period	3	22.509	3	22.509
Treatment	3	86.982	-	-
Fiber	-	-	1	104.194
Protein	-	-	1	31.753
Fiber * Protein	-	-	1	125.001
Error	30	21.492	30	21.492

TABLE 112. ANALYSIS OF VARIANCE FOR ILEAL GLUTAMIC ACID DIGESTIBILITY (EXP. 3)

	Overall analysis of variance		Factorial analysis of variance	
Source	df	Mean Square	df	Mean Square
Total	47	8.790	47	8.790
Pig	11	5.078	11	5.078
Period	3	21.901	3	21.901
Treatment	3	8.262	-	-
Fiber	-	-	1	.354
Protein	-	-	1	6.645
Fiber * Protein	-	-	1	17.788
Error	30	8.893	30	8.893

TABLE 113. ANALYSIS OF VARIANCE FOR ILEAL GLYCINE DIGESTIBILITY (EXP. 3)

	Overall analysis of variance		Factorial analysis of variance	
Source	df	Mean Square	df	Mean Square
Total	47	42.679	47	42.679
Pig	11	24.633	11	24.633
Period	3	43.918	3	43.918
Treatment	3	363.404	-	-
Fiber	-	-	1	1073.332
Protein	-	-	1	6.556
Fiber * Protein	-	-	1	10.323
Error	30	17.099	30	17.099

TABLE 114. ANALYSIS OF VARIANCE FOR ILEAL ALANINE DIGESTIBILITY (EXP. 3)

	Overall analysis of variance		Factorial analysis of variance	
Source	df	Mean Square	df	Mean Square
Total	47	25.674	47	25.674
Pig	11	14.550	11	14.550
Period	3	28.582	3	28.582
Treatment	3	30.622	-	-
Fiber	-	-	1	.927
Protein	-	-	1	3.702
Fiber * Protein	-	-	1	87.237
Error	30	28.967	30	28.967

TABLE 115. ANALYSIS OF VARIANCE FOR ILEAL VALINE DIGESTIBILITY (EXP. 3)

	Overall analysis of variance		Factorial analysis of variance	
Source	df	Mean Square	df	Mean Square
Total	47	22.272	47	22.272
Pig	11	14.637	11	14.637
Period	3	51.695	3	51.695
Treatment	3	6.654	-	-
Fiber	-	-	1	2.911
Protein	-	-	1	1.527
Fiber * Protein	-	-	1	15.527
Error	30	23.691	30	23.691

TABLE 116. ANALYSIS OF VARIANCE FOR ILEAL ISOLEUCINE DIGESTIBILITY (EXP. 3)

	Overall analysis of variance		Factorial analysis of variance	
Source	df	Mean Square	df	Mean Square
Total	47	27.084	47	27.084
Pig	11	19.516	11	19.516
Period	3	23.295	3	23.295
Treatment	3	21.009	-	-
Fiber	-	-	1	5.142
Protein	-	-	1	.002
Fiber * Protein	-	-	1	57.882
Error	30	30.845	30	30.845

TABLE 117. ANALYSIS OF VARIANCE FOR ILEAL LEUCINE DIGESTIBILITY (EXP. 3)

	Overall analysis of variance		Factorial analysis of variance	
Source	df	Mean Square	df	Mean Square
Total	47	17.200	47	17.200
Pig	11	10.851	11	10.851
Period	3	13.684	3	13.684
Treatment	3	4.866	-	-
Fiber	-	-	1	.104
Protein	-	-	1	12.515
Fiber * Protein	-	-	1	1.980
Error	30	21.113	30	21.113

TABLE 118. ANALYSIS OF VARIANCE FOR ILEAL TYROSINE DIGESTIBILITY (EXP. 3)

	Overall analysis of variance		Factorial analysis of variance	
Source	df	Mean Square	df	Mean Square
Total	47	534.549	47	534.549
Pig	11	345.407	11	345.407
Period	3	319.828	3	319.828
Treatment	3	1242.408	-	-
Fiber	-	-	1	81.458
Protein	-	-	1	3637.820
Fiber * Protein	-	-	1	7.946
Error	30	554.587	30	554.587

TABLE 119. ANALYSIS OF VARIANCE FOR ILEAL PHENYLALANINE DIGESTIBILITY (EXP. 3)

	Overall analysis of variance		Factorial analysis of variance	
Source	df	Mean Square	df	Mean Square
Total	47	30.046	47	30.046
Pig	11	14.138	11	14.138
Period	3	2.175	3	2.175
Treatment	3	41.594	-	-
Fiber	-	-	1	44.198
Protein	-	-	1	.347
Fiber * Protein	-	-	1	80.238
Error	30	37.511	30	37.511

TABLE 120. ANALYSIS OF VARIANCE FOR ILEAL LYSINE DIGESTIBILITY (EXP. 3)

	Overall analysis of variance		Factorial analysis of variance	
Source	df	Mean Square	df	Mean Square
Total	47	42.616	47	42.616
Pig	11	29.547	11	29.547
Period	3	36.111	3	36.111
Treatment	3	118.221	-	-
Fiber	-	-	1	269.896
Protein	-	-	1	4.839
Fiber * Protein	-	-	1	79.928
Error	30	40.498	30	40.498

TABLE 121. ANALYSIS OF VARIANCE FOR ILEAL HISTIDINE DIGESTIBILITY (EXP. 3)

	Overall analysis of variance		Factorial analysis of variance	
Source	df	Mean Square	df	Mean Square
Total	47	30.803	47	30.803
Pig	11	15.644	11	15.644
Period	3	28.581	3	28.581
Treatment	3	125.287	-	-
Fiber	-	-	1	171.423
Protein	-	-	1	112.945
Fiber * Protein	-	-	1	91.494
Error	30	27.134	30	27.134

TABLE 122. ANALYSIS OF VARIANCE FOR ILEAL ARGININE DIGESTIBILITY (EXP. 3)

	Overall analysis of variance		Factorial analysis of variance	
Source	df	Mean Square	df	Mean Square
Total	47	7.878	47	7.878
Pig	11	5.528	11	5.528
Period	3	4.188	3	4.188
Treatment	3	17.303	-	-
Fiber	-	-	1	1.606
Protein	-	-	1	7.776
Fiber * Protein	-	-	1	42.526
Error	30	8.166	30	8.166

TABLE 123. ANALYSIS OF VARIANCE FOR FECAL ASPARTIC ACID DIGESTIBILITY (EXP. 3)

	Overall analysis of variance		Factorial analysis of variance	
Source	df	Mean Square	df	Mean Square
Total	47	30.683	47	30.683
Pig	11	32.309	11	32.309
Period	3	90.706	3	90.706
Treatment	3	186.410	-	-
Fiber	-	-	1	535.669
Protein	-	-	1	3.137
Fiber * Protein	-	-	1	20.423
Error	30	8.512	30	8.512

TABLE 124. ANALYSIS OF VARIANCE FOR FECAL THREONINE DIGESTIBILITY (EXP. 3)

	Overall analysis of variance		Factorial analysis of variance	
Source	df	Mean Square	df	Mean Square
Total	47	55.821	47	55.821
Pig	11	42.017	11	42.017
Period	3	173.824	3	173.824
Treatment	3	381.283	-	-
Fiber	-	-	1	1088.422
Protein	-	-	1	.281
Fiber * Protein	-	-	1	55.148
Error	30	16.535	30	16.535

TABLE 125. ANALYSIS OF VARIANCE FOR FECAL SERINE DIGESTIBILITY (EXP. 3)

	Overall analysis of variance		Factorial analysis of variance	
Source	df	Mean Square	df	Mean Square
Total	47	26.516	47	26.516
Pig	11	24.781	11	24.781
Period	3	55.865	3	55.865
Treatment	3	205.980	-	-
Fiber	-	-	1	557.944
Protein	-	-	1	40.425
Fiber * Protein	-	-	1	19.571
Error	30	6.271	30	6.271

TABLE 126. ANALYSIS OF VARIANCE FOR FECAL GLUTAMIC ACID DIGESTIBILITY (EXP. 3)

	Overall analysis of variance		Factorial analysis of variance	
Source	df	Mean Square	df	Mean Square
Total	47	9.896	47	9.896
Pig	11	14.194	11	14.194
Period	3	20.977	3	20.977
Treatment	3	50.104	-	-
Fiber	-	-	1	148.579
Protein	-	-	1	1.330
Fiber * Protein	-	-	1	.402
Error	30	3.191	30	3.191

TABLE 130. ANALYSIS OF VARIANCE FOR FECAL ISOLEUCINE DIGESTIBILITY (EXP. 3)

	Overall analysis of variance		Factorial analysis of variance	
Source	df	Mean Square	df	Mean Square
Total	47	67.495	47	67.495
Pig	11	54.434	11	54.434
Period	3	419.875	3	419.875
Treatment	3	179.855	-	-
Fiber	-	-	1	398.765
Protein	-	-	1	37.224
Fiber * Protein	-	-	1	103.576
Error	30	25.810	30	25.810

TABLE 131. ANALYSIS OF VARIANCE FOR FECAL LEUCINE DIGESTIBILITY (EXP. 3)

	Overall analysis of variance		Factorial analysis of variance	
Source	df	Mean Square	df	Mean Square
Total	47	36.754	47	36.754
Pig	11	35.289	11	35.289
Period	3	242.963	3	242.963
Treatment	3	73.110	-	-
Fiber	-	-	1	170.027
Protein	-	-	1	48.803
Fiber * Protein	-	-	1	.500
Error	30	13.036	30	13.036

TABLE 132. ANALYSIS OF VARIANCE FOR FECAL TYROSINE DIGESTIBILITY (EXP. 3)

	Overall analysis of variance		Factorial analysis of variance	
Source	df	Mean Square	df	Mean Square
Total	47	559.902	47	559.902
Pig	11	232.496	11	232.496
Period	3	2769.225	3	2769.225
Treatment	3	3509.704	-	-
Fiber	-	-	1	125.745
Protein	-	-	1	9864.487
Fiber * Protein	-	-	1	538.881
Error	30	164.039	30	164.039

TABLE 133. ANALYSIS OF VARIANCE FOR FECAL PHENYLALANINE DIGESTIBILITY (EXP. 3)

	Overall analysis of variance		Factorial analysis of variance	
Source	df	Mean Square	df	Mean Square
Total	47	57.036	47	57.036
Pig	11	34.308	11	34.308
Period	3	446.080	3	446.080
Treatment	3	123.333	-	-
Fiber	-	-	1	181.002
Protein	-	-	1	42.244
Fiber * Protein	-	-	1	146.755
Error	30	19.835	30	19.835

TABLE 134. ANALYSIS OF VARIANCE FOR FECAL LYSINE DIGESTIBILITY (EXP. 3)

	Overall analysis of variance		Factorial analysis of variance	
Source	df	Mean Square	df	Mean Square
Total	47	112.516	47	112.516
Pig	11	95.867	11	95.867
Period	3	700.948	3	700.948
Treatment	3	486.892	-	-
Fiber	-	-	1	1364.374
Protein	-	-	1	17.581
Fiber * Protein	-	-	1	78.72
Error	30	22.340	30	22.340

TABLE 135. ANALYSIS OF VARIANCE FOR FECAL HISTIDINE DIGESTIBILITY (EXP. 3)

	Overall analysis of variance		Factorial analysis of variance	
Source	df	Mean Square	df	Mean Square
Total	47	74.223	47	74.223
Pig	11	55.564	11	55.564
Period	3	494.421	3	494.421
Treatment	3	247.940	-	-
Fiber	-	-	1	429.304
Protein	-	-	1	189.806
Fiber * Protein	-	-	1	124.711
Error	30	21.673	30	21.673

TABLE 136. ANALYSIS OF VARIANCE FOR FECAL ARGININE DIGESTIBILITY (EXP. 3)

	Overall analysis of variance		Factorial analysis of variance	
Source	df	Mean Square	df	Mean Square
Total	47	29.511	47	29.511
Pig	11	26.111	11	26.111
Period	3	196.061	3	196.061
Treatment	3	56.766	-	-
Fiber	-	-	1	74.227
Protein	-	-	1	43.339
Fiber * Protein	-	-	1	52.371
Error	30	11.377	30	11.377